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PEDCO-Environmental Specialists, Inc.

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June 1976

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The report gives procedures for estimating the capital costs and annualized operating costs for five flue gas desulfurization (FGD) systems: lime, wet limestone, magnesium oxide, Wellman-Lord, and double alkali. Two methods are given for calculating the costs for the five systems: a detailed, flexible nomograph procedure, and a rapid equation procedure. All items that affect the capital and annualized operating costs of FGD systems in these estimating procedures are identified. Costs estimated by the procedures are compared with actual costs incurred by FGD system operators. Any differences between the estimated and actual costs are accounted for; the estimating procedures are modified when necessary.

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SIMPLIFIED PROCEDURES FOR ESTIMATING FLUE GAS DESULFURIZATION SYSTEM COSTS

by

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1. INTRODUCTION

This study was sponsored by the U.S. Environmental Protection Agency to provide assistance to EPA's Industrial Environmental Research Laboratory at Research Triangle Park (IERL-RTP) in economic comparisons of flue gas desulfurization (FGD) systems.

The primary objective is to identify all items that affect the capital and annualized operation costs of FGD systems. Direct capital costs cover such items as equipment, piping, electrical and structural materials, site development, insulation, and painting; indirect costs cover such items as interest, engineering expenses, contractor fees, taxes, and contingency costs. Annualized operating cost items include raw materials, utilities, operating labor, capital charges, insurance, taxes, and depreciation.

A second objective of this study is to prepare procedures for estimating the capital costs and the annualized operating costs of five FGD systems: lime, wet limestone, magnesium oxide, Wellman-Lord, and double alkali.

A third objective is to compare the costs estimated by these procedures with actual costs incurred by operators of selected FGD installations. Any differences between the estimated and the actual costs are accounted for, and the estimating procedures modified when necessary.

Section 2 presents the various cost elements comprising total installed capital and annualized operating costs of FGD systems.

Section 3 identifies the characteristics of 12 model plants for use in these analyses and develops cost values for the lime, limestone, magnesium oxide, Wellman-Lord, and double alkali systems at these model plants.

Section 4 compares costs derived by use of the cost estimating procedures developed in this study with costs of actual and planned installations as reported by industrial users.

Input data required for use of estimating procedures are presented in Section 5, with discussion of cost updating methods and retrofit difficulty factors. Detailed cost estimating manuals are presented for the five FGD processes in Appendices A through E. Simplified procedures for rapid estimation of capital and annualized FGD costs are given in Appendix F.

2. COST COMPONENTS FOR FLUE GAS DESULFURIZATION SYSTEMS

Total costs of flue gas desulfurization systems include both capital and annualized costs. Capital costs are direct and indirect. Direct costs are those of plant equipment, instrumentation, piping, electrical and structural materials, site work, insulation, painting, and piling, and the accompanying costs of installation or application. Indirect costs include interest assessed during construction; contractors fees and expenses; engineering, freight, and off-site expenses; and taxes and allowances; and contingencies.

Annualized operating costs are both fixed and variable. Variable costs include those of utilities, labor, maintenance, and in some cases overhead. Fixed costs include those of depreciation, interim replacement, insurance, taxes, and capital charges. The various components of capital and annualized costs are discussed in greater detail in Sections 2.1 and 2.2.

2.1 CAPITAL COST COMPONENTS

The major capital cost components of an FGD system consist of plant equipment, installation, site development and indirect costs.

2.1.1 Plant Equipment, Installation, and Site Development Costs

Table 2-1 lists the major process equipment required for FGD systems. Installation of this equipment requires foundations; steel work for support; buildings; piping and ducting for effluents, slurries, sludge, steam, overflows, acid, drainage, and make-up water; control panels; instrumentation; insulation of ducting, buildings, piping, and other equipment; painting; and in some instances, piling. Site development includes right-of-way for sludge disposal; site clearing and grading; construction of access roads and walkways; establishment of rail, barge, or truck facilities; parking facilities; landscaping; and fencing.

2.1.2 Indirect Costs

Indirect costs include the following elements:

Land required for the FGD process, including a sludge waste or regeneration facility, storage, and right-of-ways.

Interest accrued during construction on borrowed capital.

Contractor's fee and expenses, including costs for field labor payroll; supervision field office; personnel; construction offices; temporary roadways; railroad trackage; maintenance and weld shops; parking lot; communication; temporary piping and electrical and sanitary facilities; safety security of all types--fire, material, medical, etc; construction tools and rental equipment; unloading and storage of materials; travel expenses; permits; licenses; taxes; insurance; overhead; legal liabilities; field testing of equipment; start-up; and labor relations.

Table 2-1. MAJOR FGD SYSTEM EQUIPMENT SUMMARY

Equipment	Description
Material handling-raw materials	Equipment for the handling and transfer of raw materials includes unloading facilities, conveyors, storage areas and silos, vibrators, atmospheric emission control associated with these facilities, and related accessories.
Feed preparation-raw materials	Equipment for the preparation of raw materials to produce a scrubbing slurry consists of feed weighers, crushers, grinders, classifiers, ball mills, mixing tanks, pumps, agitators, and related accessories.
SO_2 scrubbing	Equipment of a nonregenerative system for scrubbing the SO_2-laden flue gas includes scrubbers, demisters, effluent hold tanks, agitators, circulating pumps, pond water return pumps, and related accessories. In addition, scrubbing equipment for a regenerative system includes convertor, catalyst storage, conveyors, and related accessories.
Flue gas reheat	To increase plume buoyancy and minimize condensation the scrubber exhaust gas is heated from about 125° to 175°F. Equipment required includes an economizer, air/steam or fluid heaters, condensate tanks, pumps, soot blower, and related accessories.
Gas handling	Equipment to handle the boiler flue gas includes booster fans, ductwork, flue gas bypass system, turning vanes, supports, platforms, and related accessories.
Sludge disposal	Nonregenerative FGD systems require a clarifier, pumps, vacuum filtration, sludge fixation equipment, and related accessories.
Utilities	Equipment to supply power to the FGD equipment consists of switch-gear, breakers, transformers, and related accessories.
Cake processing	Equipment for processing the by-product of regenerative FGD systems includes a rotary kiln, fluid bed dryer, conveyor, storage silo ($MgSO_3$, etc.), vibrator, combustion equipment and oil storage tanks, waste heat boiler, hammer mills etc. Or, evaporators, crystallizers, strippers, tanks, agitators, pumps, compressors, etc. Or H_2SO_4 absorber and cooling, mist eliminator, pumps, acid coolers, tanks, etc.
Regeneration	Equipment for regeneration of the scrubber medium of a regenerative system consists of: coke material handling system, storage, weight feeder, conveyor, rotary kiln, fluid bed calciner, dust collector, storage silo (MgO, etc.), vibrator, combustion equipment and oil storage tanks, waste heat boiler, hammer mill, etc. Or, evaporators, crystallizers, strippers, tanks, agitators, pumps, compressors, etc. Or H_2SO_4 absorber and cooling, mist eliminator, pumps, acid coolers, tanks, etc.
Purge treatment	Equipment for the removal of sodium sulfate includes refrigeration, pumps, tanks, crystallizer, centrifuge, dryer, dust collector, conveyors, storage, and related equipment.

Engineering costs, including administrative, process, project, and general; design and related functions for specifications; bid analysis; special studies; cost analysis; accounting; reports; consultant fees; purchasing; procurement; travel expenses; living expenses; expediting; inspection; safety; communications; modeling; pilot plant studies; royalty payments during construction; training of plant personnel; field engineering; safety engineering; and consultant services.

Legal expenses, including those for securing permits, right-of-way sections, etc.

Freight, including delivery costs on FGD process and related equipment shipped F.O.B.

Off-site expenditures, including those for power house modifications; interruption to power generation; and service facilities added to the existing plant facilities.

Taxes, including sales, franchise, property, and excise taxes.

Insurance, covering liability for equipment shipped and at site; fire, other casualty, personal injury, death; damage to property; embezzlement; delay; and noncompliance.

Shakedown and contingency costs, including those of malfunctions; alterations to design equipment; premium time for repairs; start-up utilities; start-up materials for process; price changes due to inflation; and wage scale increases.

Spare parts stock to permit 100 percent process availability, including pumps, valves, controls, special piping and fittings, instruments, spray nozzles, and similar items.

2.2 ANNUAL OPERATING COSTS

Annual operating costs of a flue gas desulfurization system include the following elements:

Raw materials, including those required by the FGD process for sulfur dioxide control, system loss, and sludge fixation.

Utilities, including water for slurries, cooling and cleaning; electricity for pumps, fans, valves, lighting controls, conveyors, and mixers; fuel for reheating of flue gases; and steam for FGD process.

Maintenance and repairs, consisting of both manpower and materials to keep the unit operating efficiently. The function of maintenance is both preventive and corrective to keep outages to a minimum.

Overhead, a business expense that is not charged directly to a particular part of a process, but is allocated to it. Overhead costs include administrative, safety, engineering, legal, and medical services, payroll; employee benefits; recreation; and public relations.

Fixed charges, which continue for the estimated life of the process, including costs of the following:

- Depreciation - the charge for losses in physical assests due to deterioration (wear and tear, erosion and corrosion) and other factors, such as technical changes that make physical assets obsolete.
- Interim replacement - costs expended during the year for temporary or provisional replacement of equipment that has failed or malfunctioned.
- Insurance - costs of protection from loss by a specified contingency, peril, or unforeseen event. Required coverage could include losses due to fire, personal injury or death, property damage, embezzlement, explosion, lightning, or other natural phenomena.
- Taxes, including franchise, excise, and property taxes leveed by a city, county, state, or Federal government.
- Capital costs due to interest on borrowed funds.

3. RELATIVE COSTS OF FLUE GAS DESULFURIZATION SYSTEMS

3.1 COSTS OF FGD SYSTEMS AT MODEL PLANTS

The capital and annualized costs of FGD systems can vary significantly depending upon design and site-specific factors. Factors having a major cost impact are plant size (capacity), remaining life, and capacity factor; FGD process and design; sulfur content and heating values of the coal; maximum allowable SO_2 emission rate; status of FGD installation (new plant or retrofit); particulate control requirements; and replacement power requirements.

As a means of developing cost estimates and illustrating the impacts of site and process factors on capital and annualized costs of different FGD systems, 12 models of 'typical' utilities plants are defined. The 12 model plants incorporate three variable cost elements: plant size (capacity), installation status, and degree of SO_2 control required. The designated boiler capacities of 250, 500, and 1000 MW cover a size range representative of U.S. power plant boilers. Both new plant and retrofit applications are considered for each plant size. Further, each plant size is analyzed in terms of two SO_2 control requirements: use of high-sulfur coal (3.5% S) with an SO_2 limitation of 1.2 lb/10^6 Btu (Federal New Source Performance Standard), and use of low-sulfur coal (0.6% S) with an SO_2 limitation of 0.15 lb/10^6 Btu (stringent local SO_2 regulations such as Clark County, Nevada).

Other variables such as remaining plant life and plant capacity factor are selected to be representative of each model plant. Operating costs for such components as raw materials and utilities, which vary with geographical location, are considered to be representative of a midwest location. Table 3-1 identifies the characteristics and major assumptions for the model plants.

Cost summaries based on the model plant characteristics are developed for each of the five FGD systems in the following sections. These costs are in January 1975 dollars; they do not include escalation during the project period.

3.1.1 Lime Scrubbing System

The lime scrubbing system, as shown in Figure 3-1, utilizes a lime slurry as the sulfur dioxide absorbent medium. The sulfur dioxide reacts with the limestone to form calcium sulfite ($CaSO_3$), which is removed from the system as a waste product. Flue gases from the boiler pass through an electrostatic precipitator or venturi scrubber

Table 3-1. SUMMARY OF CHARACTERISTICS AND ASSUMPTIONS FOR MODEL PLANTS

Model plant parameters	Characteristics and assumptions			
Plant capacities, megawatts	250, 500, and 1000 (single boilers)			
Plant status	New and existing (retrofit)			
Coal characteristics	Low sulfur coal: 0.6% S, 9000 Btu/lb High sulfur coal: 3.5% S, 12,000 Btu/lb			
SO_2 control requirement	Low sulfur coal: 0.15 lb/10^6 Btu High sulfur coal: 1.2 lb/10^6 Btu (Federal New Source Performance Standard)			
Location	Midwest Location-East North Central Region			
Boiler data				
Capacity factor	Assumed 0.6 for all 12 plants			
Heat rates, flue gas flow rates and remaining life	Capacity, MW	Heat rate,[1] Btu/kWh	Flue gas[1] flow rate, acfm/MW	Remaining boiler life, yr.
	250 new	9,200	3,175	35
	250 existing	9,500	3,275	15
	500 new	9,200	3,080	35
	500 existing	9,200	3,140	20
	1000 new	8,700	2,980	35
	1000 existing	9,000	3,080	25
Flue gas temperature	Assumed 310°F for all plants			

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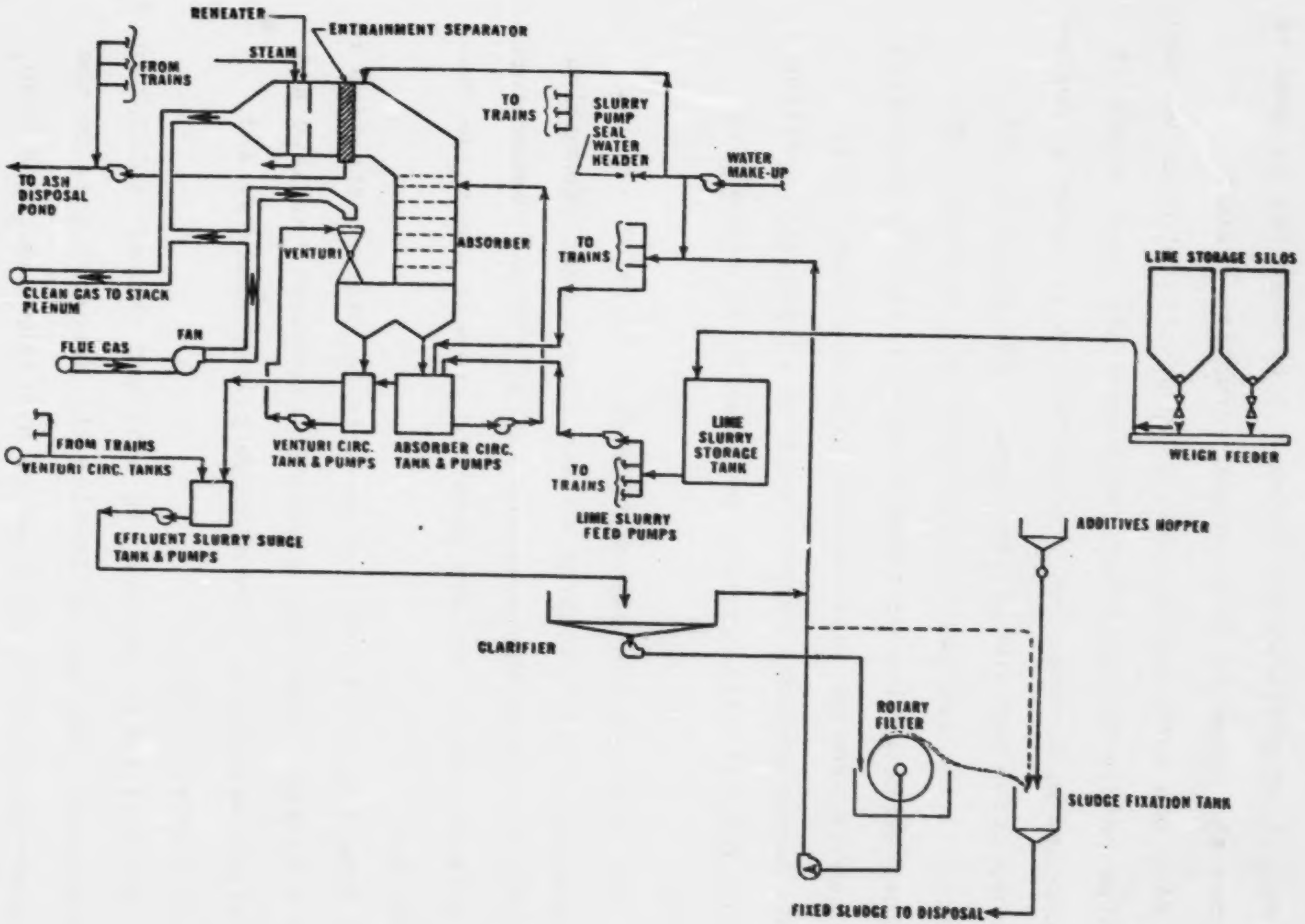
[1] Detailed Cost Estimated for Advanced Effluent Desulfurization Processes, prepared for Control Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, under Interagency Agreeement EPA IAG-134(d) Part A, by G.G. McGlanery, et al., Tennessee Valley Authority, pp. 65,60. May 1974.

Table 3-1 (continued). SUMMARY OF CHARACTERISTICS AND ASSUMPTIONS FOR MODEL PLANTS

Model plant parameters	Characteristics and assumptions
Operating cost factors	Based on East North Central Regional averages
Raw materials	
Lime cost	$20.00/ton delivered
Limestone cost	$6.00/ton delivered
Soda ash cost (Wellman-Lord)	$55.00/ton
Sulfuric acid credit (Wellman-Lord)	$20.00/ton
Salt cake credit (Wellman-Lord)	$40.00/ton
Electricity cost	15 mills/kWh
Taxes	4%
Capital cost	9%
Sludge disposal	Assumed on-site disposal of stabilized (fixed) sludge.
FGD system life	Assumed 20 years for depreciation purposes.
Retrofit characteristics	Longer duct runs, tight space constraints, increased construction labor costs.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ADDITIVES HOPPER
CLARIFIER
ROTARY FILTER
SLUDGE FIXATION TANK
FIXED SLUDGE TO DISPOSAL

Figure 3-1. Lime slurry system.

for removal of particulate matter. A booster fan is used to overcome the pressure drop in the scrubbing system.

Flue gas from the electrostatic precipitator or venturi scrubber enters the absorber tower near the base, where it is quenched with water for cooling before it ascends through the absorption section of the tower. Quenching is not required if the absorber is preceded by a venturi. The absorber contains two or three stages, where the ascending flue gas is brought into contact with the lime slurry. Solids concentrations range from [illegible] to 15 percent. Sulfur dioxide removal efficiencies are usually 85 percent or greater.

The scrubbed gas passes through a demister and is reheated prior to discharge to the atmosphere. Reheating provides for plume buoyancy and raises the gas temperature sufficiently above the dew point to prevent excessive condensation.

Lime slurry is prepared on-site by slaking the lime to form a slurry. The lime system incorporates handling and conveying equipment, lime storage silos, slakers, and slurry storage tanks.

Partial water recovery is achieved through solid/liquid separations. The slurry leaving the absorber goes to the absorber-circulation tank, where hydrated $CaSO_3$ and $CaSO_4$

crystals are precipitated. A bleed stream carries these solids to a gravity clarifier, where the crystals, fly ash, and unreacted lime settle. The overflow from the clarifier and the filtrate return to the circulation tank. The underflow from the clarifier is filtered in a rotary filter to produce a sludge with a moisture content of about 60 percent. The sludge is stabilized (fixed) with chemical additives in a mixing tank to prevent leaching, then is pumped or trucked to a permanent disposal site.

Capital and annualized model plant costs for the lime scrubbing system are shown in Table 3-2.

3.1.2 Limestone Scrubbing System

The limestone scrubbing system, as shown in Figure 3-2, utilizes a limestone ($CaCO_3$) slurry as the sulfur dioxide absorbent medium. The process is the same as that of the lime scrubbing system just described, except that limestone slurry is prepared on-site by a wet ball milling process to reduce crushed limestone to a slurry in which 95 percent of the particles are less than 325 mesh. The limestone system requires an open limestone storage area, handling and conveying equipment, limestone storage silos, wet ball mills, and slurry storage tanks.

Process steps entailing the circulation tank, the clarifier, and equipment used in the production, treatment,

Table 3-2. LIME SCRUBBING COSTS

Model plant characteristics	Capital,		Operating and maintenance, mills/kWh	Annualized Fuel and electricity, mills/kWh	Fixed costs, mills/kWh	Total,	
	$/kW	$ MM				mills/kWh	$ MM
250 megawatt capacity							
Retrofit, 3.5% S	76.64	19.16	2.785	0.484	3.885	7.154	9.400
New, 3.5% S	64.29	16.07	2.256	0.484	2.483	5.223	6.863
Retrofit, 0.6% S	63.78	15.95	1.696	0.566	3.241	5.503	7.231
New, 0.6% S	51.92	12.98	1.230	0.566	2.000	3.796	4.988
500 megawatt capacity							
Retrofit, 3.5% S	62.52	31.27	2.137	0.466	2.416	5.020	13.193
New, 3.5% S	53.90	26.95	2.024	0.466	2.082	4.572	12.015
Retrofit, 0.6% S	53.42	26.71	1.155	0.532	2.063	3.751	9.858
New, 0.6% S	48.17	24.09	1.086	0.532	1.860	3.478	9.140
1000 megawatt capacity							
Retrofit, 3.5% S	53.08	53.08	1.903	0.476	2.050	4.429	23.279
New, 3.5% S	48.94	48.94	1.849	0.476	1.890	4.215	22.154
Retrofit, 0.6% S	50.44	50.44	1.053	0.544	1.948	3.545	18.633
New, 0.6% S	44.21	44.21	0.971	0.544	1.708	3.223	16.940

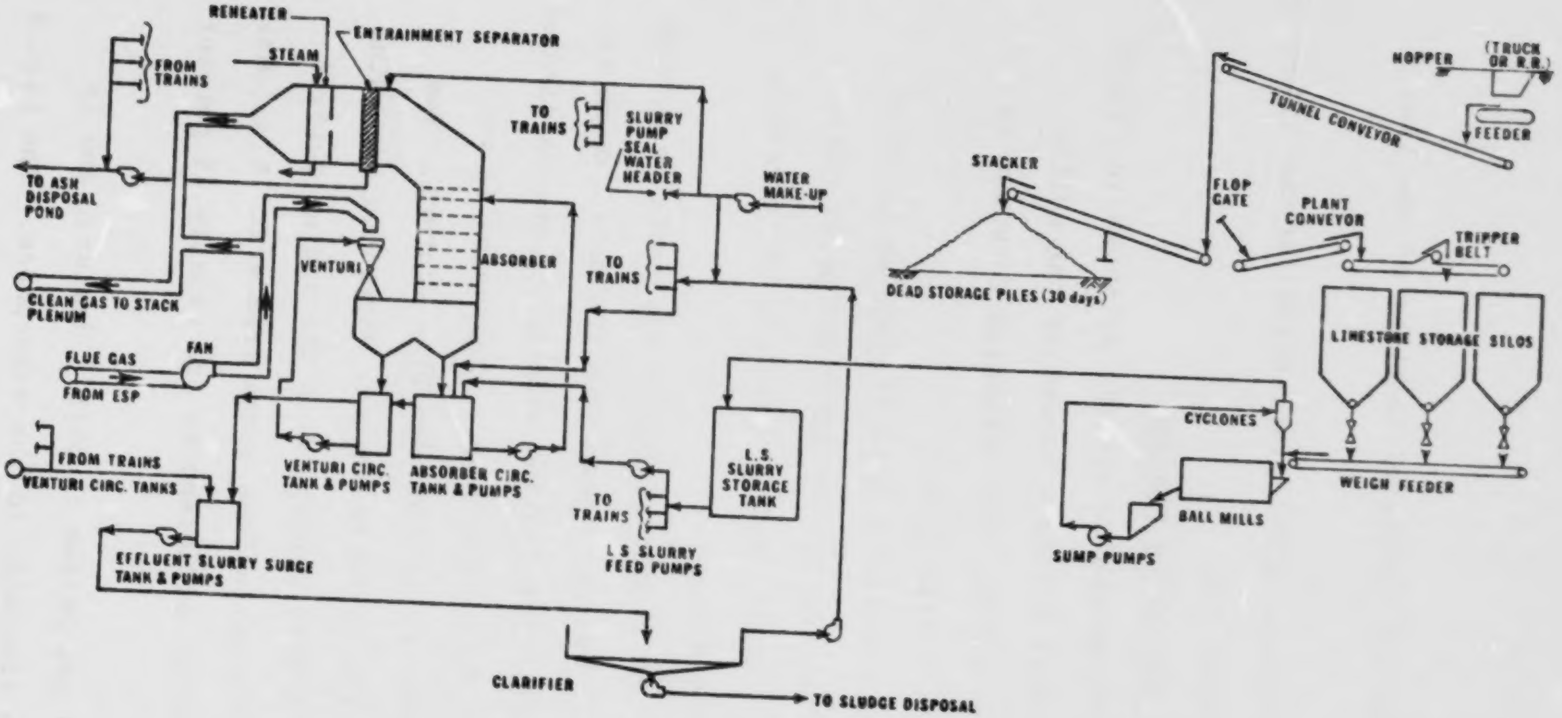
REHEATER
ENTRAINMENT SEPARATOR
STEAM
FROM TRAINS
TO ASH DISPOSAL POND
CLEAN GAS TO STACK PLENUM
FLUE GAS FROM ESP
FAN
VENTURI
ABSORBER
FROM TRAINS
VENTURI CIRC. TANKS
VENTURI CIRC. TANK & PUMPS
ABSORBER CIRC. TANK & PUMPS
EFFLUENT SLURRY SURGE TANK & PUMPS
TO TRAINS
SLURRY PUMP SEAL WATER HEADER
WATER MAKE-UP
TO TRAINS
TO TRAINS
L.S. SLURRY STORAGE TANK
L.S. SLURRY FEED PUMPS
CLARIFIER
TO SLUDGE DISPOSAL
STACKER
DEAD STORAGE PILES (30 days)
FLOP GATE
TUNNEL CONVEYOR
HOPPER
(TRUCK OR R.R.)
FEEDER
PLANT CONVEYOR
TRIPPER BELT
LIMESTONE STORAGE SILOS
CYCLONES
WEIGH FEEDER
BALL MILLS
SUMP PUMPS

Figure 3-2. Limestone slurry system.

and disposal of sludge are identical to those of the lime system.

Capital and annualized model plant costs for the limestone are shown in Table 3-3.

3.1.3 Double Alkali Scrubbing System

The double alkali scrubbing system, as shown in Figure 3-3, uses sodium sulfite solution to remove the sulfur dioxide from the flue gases. The scrubbing solution is regenerated by reaction with lime.

Flue gases from the boiler pass through an electrostatic precipitator or venturi scrubber for particulate removal. A booster fan is used to overcome the pressure drop in the scrubbing system.

Flue gas from the electrostatic precipitator or venturi scrubber enters the absorber tower near the base, where it is quenched with water for cooling before it ascends through the absorption section of the tower. Quenching is not required if the absorber is preceded by a venturi. The absorber contains two or three stages, where the ascending flue gas is brought into contact with the sodium sulfite solution. Solid concentrations range from 4 to 15 percent. Sulfur dioxide removal efficiencies are usually 85 percent or greater.

The scrubbed gas passes through a demister and is reheated prior to discharge to the atmosphere. The liquid

Table 3-3. LIMESTONE SCRUBBING COSTS

Model plant characteristics	Capital, $/kW	Capital, $ MM	Operating and maintenance, mills/kWh	Annualized Fuel and electricity, mills/kWh	Fixed costs, mills/kWh	Total, mills/kWh	Total, $ MM
250 megawatt capacity							
Retrofit, 3.5% S	90.92	22.73	1.967	0.516	3.511	5.994	7.876
New, 3.5% S	77.08	19.27	1.795	0.516	2.975	5.286	6.946
Retrofit, 0.6% S	73.33	18.83	1.342	0.586	2.832	4.760	6.255
New, 0.6% S	59.94	14.99	1.165	0.586	2.314	4.065	5.341
500 megawatt capacity							
Retrofit, 3.5% S	71.61	35.81	1.624	0.499	2.766	4.889	12.848
New, 3.5% S	62.59	31.30	1.473	0.499	2.416	4.388	11.531
Retrofit, 0.6% S	62.95	31.48	1.398	0.586	2.432	4.388	11.531
New, 0.6% S	54.28	27.14	0.992	0.586	2.093	3.671	9.647
1000 megawatt capacity							
Retrofit, 3.5% S	70.11	70.11	1.530	0.499	2.707	4.736	24.892
New, 3.5% S	59.85	59.85	1.394	0.499	2.310	4.203	22.091
Retrofit, 0.6% S	54.84	54.84	0.946	0.558	2.118	3.622	19.037
New, 0.6% S	48.52	48.52	0.864	0.558	1.874	3.296	17.323

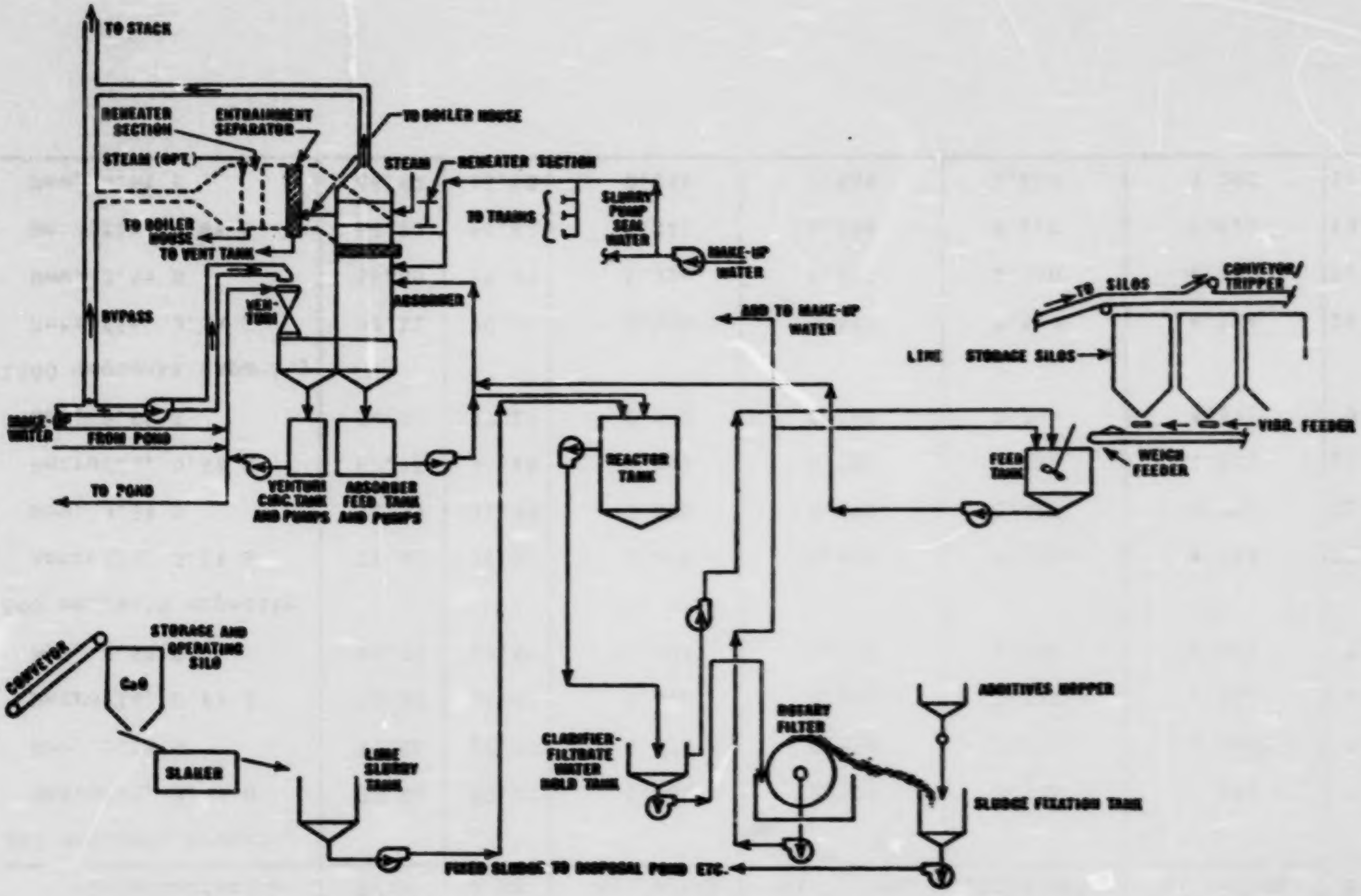
TO STACK
REHEATER SECTION
ENTRAINMENT SEPARATOR
TO BOILER HOUSE
STEAM (OPT.)
STEAM
REHEATER SECTION
TO BOILER HOUSE
TO VENT TANK
TO TRAINS
SLURRY PUMP SEAL WATER
MAKE-UP WATER
VEN-TURI
ABSORBER
BYPASS
AND TO MAKE-UP WATER
TO SILOS
CONVEYOR/ TRIPPER
LIME STORAGE SILOS
MAKE-UP WATER
FROM POND
TO POND
VENTURI CIRC. TANK AND PUMPS
ABSORBER FEED TANK AND PUMPS
REACTOR TANK
FEED TANK
WEIGH FEEDER
VIBR. FEEDER
CONVEYOR
STORAGE AND OPERATING SILO
CaO
SLAKER
LIME SLURRY TANK
CLARIFIER-FILTRATE WATER HOLD TANK
ROTARY FILTER
ADDITIVES HOPPER
SLUDGE FIXATION TANK
FIXED SLUDGE TO DISPOSAL POND ETC.

Figure 3-3. Double alkali system.

stream containing sulfur dioxide, which has reacted with the sodium sulfite, and some fly ash enters a tank. Part of the liquor from this tank may be recycled to the scrubber inlet and the balance goes to a reactor/clarifier tank, in which lime and/or limestone is reacted with the liquor to regenerate the sodium sulfite. This occurs because the calcium in the lime/limestone reacts with the absorbed sulfur dioxide to form insoluble calcium sulfate. Clarified and regenerated scrubbing liquor is then recycled from this tank to the scrubber. Insoluble calcium-sulfur compounds are precipitated and removed from this clarifier tank.

A side stream from the primary clarifier is further treated in a regeneration step to treat and remove nonregenerable sodium sulfate compounds.

Limestone slurry is prepared on-site by a wet ball milling process to reduce crushed limestone to a slurry with 95 percent of the particles less than 325 mesh. The limestone system entails an open limestone storage area, handling and conveying equipment, lime storage silos, wet ball mills, and slurry storage tanks.

Capital and annualized model plant costs for double alkali are shown in Table 3-4.

Table 3-4. DOUBLE ALKALI SCRUBBING COSTS

Model plant characteristics	Capital,		Operating and maintenance, mills/kWh	Annualized Fuel and electricity, mills/kWh	Fixed costs, mills/kWh	Total,	
	$/kW	$ MM				mills/kWh	$ MM
250 megawatt capacity							
Retrofit, 3.5% S	99.54	74.87	2.124	0.590	3.844	6.558	8.617
New, 3.5% S	83.83	20.96	1.918	0.590	3.237	5.745	7.549
Retrofit, 0.6% S	89.78	22.45	1.558	0.607	3.467	5.632	7.400
New, 0.6% S	74.05	18.51	1.356	0.607	2.864	4.827	6.343
500 megawatt capacity							
Retrofit, 3.5% S	93.03	46.52	1.761	0.508	3.593	5.862	15.405
New, 3.5% S	81.88	40.94	1.615	0.508	3.163	5.286	13.892
Retrofit, 0.6% S	77.76	38.88	1.306	0.573	3.003	4.882	12.830
New, 0.6% S	66.77	33.39	1.162	0.573	2.583	4.318	11.348
1000 megawatt capacity							
Retrofit, 3.5% S	84.13	84.13	1.756	0.518	3.250	5.523	29.029
New, 3.5% S	76.09	76.09	1.650	0.517	2.939	5.106	26.837
Retrofit, 0.6% S	73.36	73.36	1.196	0.585	2.833	4.614	24.251
New, 0.6% S	54.51	54.51	0.948	0.585	2.105	3.638	19.121

3.1.4 Magnesium Oxide Scrubbing System

The magnesium oxide scrubbing system, as shown in Figure 3-4 uses a slurry of magnesium oxide to absorb sulfur dioxide. The sulfur dioxide is recovered from the magnesium salt by calcining.

The process steps are similar to those of the lime/limestone scrubbing systems in the early stages. Solids content of the magnesium oxide slurry ranges from 4 to 10 percent. Sulfur dioxide removal efficiencies are 85 percent or greater. The scrubbed gas passes through a demister and is reheated.

The bleed from the absorption system enters the centrifuge, where the crystals of magnesium sulfite, magnesium sulfate, and unreacted magnesium oxide are separated from the mother liquor. The mother liquor is returned to the absorption system and the centrifuged wet cake enters the dryer for removal of both the sulfur and bound moisture. The hot flue gas from the dryer is mixed with absorber outlet gas, and the heat content of the dryer flue gas provides reheat to the absorber outlet gas.

The anhydrous $MgSO_3$ and $MgSO_4$ mixture is then conveyed to a storage silo before transportation by covered trucks, barges, or rail cars to the recovery acid plant. The same carriers return regenerated MgO (with make-up) to an MgO

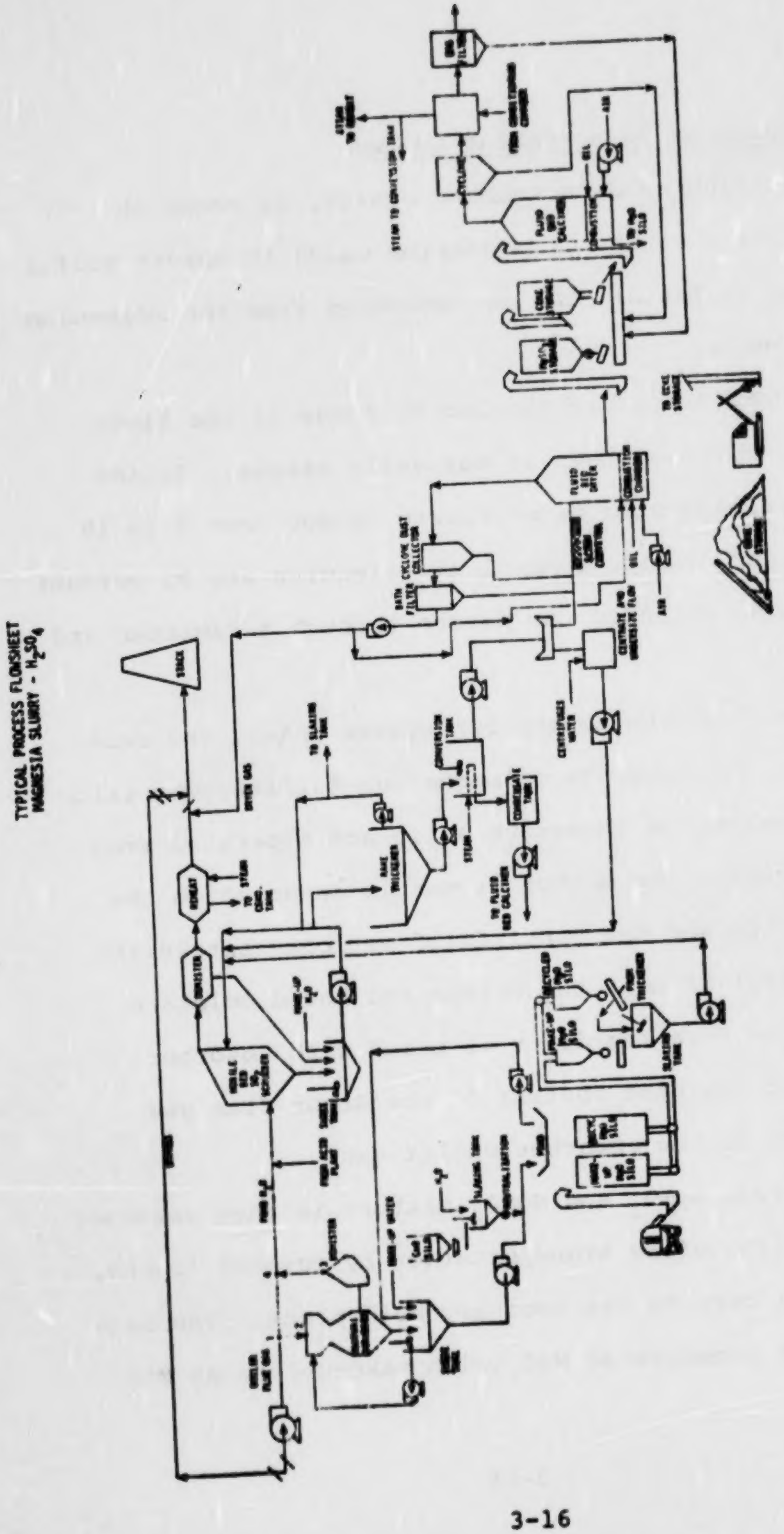
TYPICAL PROCESS FLOWSHEET
MAGNESIA SLURRY - H_2SO_4
STACK

Figure 3-4. Magnesium oxide slurry system.

silo at the power plant. The MgO slurry is prepared with regenerated MgO, make-up MgO, and make-up water. The MgO slurry is added as make-up to the absorption recycle liquid system.

The dry crystals of $MgSO_3$, $MgSO_4$, and MgO shipped by truck from the power plant are weighed and pneumatically conveyed to an $MgSO_3$ storage silo. The dry crystals are then fed to a direct-fired rotary calciner (or fluidized bed) and calcined to generate SO_2 gas and regenerate MgO. Coke is added to reduce the residual $MgSO_4$ to MgO and SO_2.

The hot flue gas containing 12 to 16 percent SO_2 and dust enters the hot cyclone, where essentially all the dust is collected and returned to the calciner. The flue gas then enters a venturi scrubber for final dust cleaning and adiabatic saturation. The saturated flue gas is cooled to 100°F in a direct-contact cooler. The cleaned, cooled flue gas enters the drying tower and the sulfuric acid plant for production of 98 percent H_2SO_4 acid. The regenerated MgO is cooled, conveyed to the MgO storage silo and recycled back to the power plant site for reuse.

Capital and annualized model plant costs for the magneisum oxide system are shown in Table 3-5.

Table 3-5. MAGNESIUM OXIDE SCRUBBING COSTS

Model plant characteristics	Capital,		Operating[a] and maintenance, mills/kWh	Annualized Fuel and electricity, mills/kWh	Fixed costs, mills/kWh	Total,	
	$/kW	$ MM				mills/kWh	$ MM
250 megawatt capacity							
Retrofit, 3.5% S	101.07	25.27	1.862	0.488	3.903	6.253	8.216
New, 3.5% S	90.80	22.70	1.727	0.478	3.507	5.712	7.506
Retrofit, 0.6% S	76.43	19.11	1.364	0.581	2.952	4.897	6.435
New, 0.6% S	62.93	15.73	1.186	0.505	2.431	4.122	5.416
500 megawatt capacity							
Retrofit, 3.5% S	84.93	42.47	1.493	0.459	2.705	4.657	12.24
New, 3.5% S	74.89	37.45	1.359	0.459	2.383	4.201	11.040
Retrofit, 0.6% S	65.43	32.72	1.067	0.529	2.527	4.123	10.835
New, 0.6% S	55.73	27.89	0.938	0.529	2.153	3.620	9.513
1000 megawatt capacity							
Retrofit, 3.5% S	76.31	76.31	1.181	0.479	2.947	4.607	24.214
New, 3.5% S	96.06	96.06	1.204	0.479	2.197	3.880	20.393
Retrofit, 0.6% S	57.62	57.62	0.942	0.517	2.225	3.684	19.363
New, 0.6% S	50.54	50.54	0.796	0.517	1.952	3.265	17.161

[a] No credits included.

3.1.5. Wellman-Lord Scrubbing System

The Wellman-Lord SO_2 recovery system, as shown in Figure 3-5, is based on the ability of an aqueous solution of sodium sulfite/bisulfite to react with sulfur dioxide at relatively low temperatures and release it when subjected to evaporation.

Flue gases from the boiler pass through an electrostatic precipitator or venturi for particulate removal. A booster fan is used to overcome the pressure drop in the scrubbing system.

Flue gas from the electrostatic precipitator or venturi enters the absorber tower near the base, where it is quenched with water for cooling before it ascends through the absorption section of the tower. Quenching is not required if the absorber is preceded by a venturi. The absorber contains two or three stages, where the ascending flue gas is brought into contact with the aqueous solution of sodium sulfite/bisulfite. The lead sodium sulfite is fed into the tower near the top and flows downward, passing through each stage countercurrently to the flow of the gas. As sulfur dioxide is absorbed in the solution, sulfite converts to bisulfite.

The scrubbed flue gas exits the absorber, passed through a demister, and is reheated before discharging to the atmosphere. More than 85 percent of the sulfur dioxide

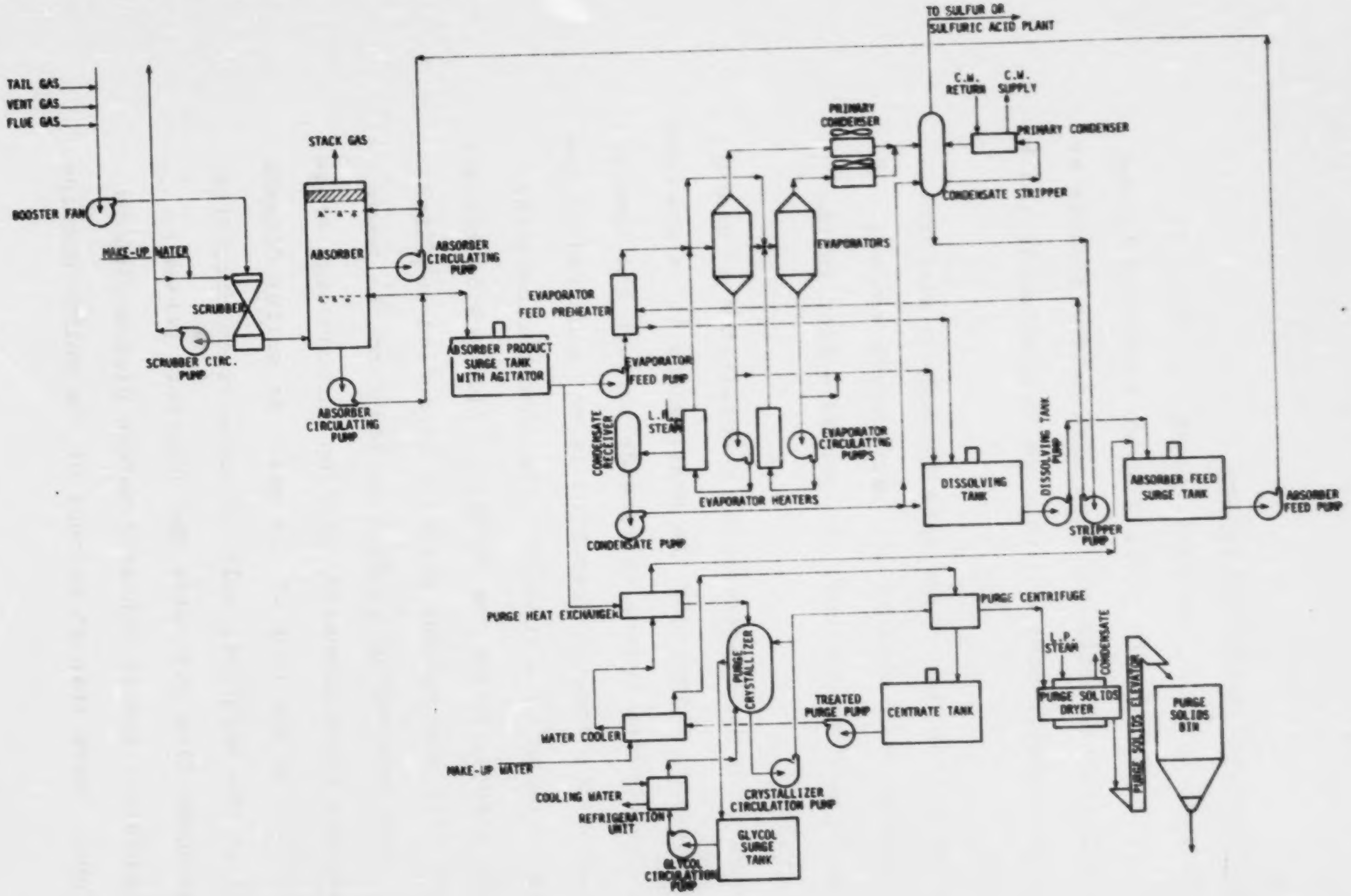
TAIL GAS
VENT GAS
FLUE GAS
BOOSTER FAN
MAKE-UP WATER
SCRUBBER
SCRUBBER CIRC. PUMP
STACK GAS
ABSORBER
ABSORBER CIRCULATING PUMP
ABSORBER CIRCULATING PUMP
ABSORBER PRODUCT SURGE TANK WITH AGITATOR
EVAPORATOR FEED PREHEATER
EVAPORATOR FEED PUMP
CONDENSATE RECEIVER
L.P. STEAM
CONDENSATE PUMP
EVAPORATOR HEATERS
EVAPORATOR CIRCULATING PUMPS
EVAPORATORS
PRIMARY CONDENSER
TO SULFUR OR SULFURIC ACID PLANT
C.W. RETURN
C.W. SUPPLY
PRIMARY CONDENSER
CONDENSATE STRIPPER
DISSOLVING TANK
DISSOLVING TANK PUMP
STRIPPER PUMP
ABSORBER FEED SURGE TANK
ABSORBER FEED PUMP
PURGE HEAT EXCHANGER
PURGE CRYSTALLIZER
PURGE CENTRIFUGE
WATER COOLER
MAKE-UP WATER
COOLING WATER
REFRIGERATION UNIT
GLYCOL CIRCULATION PUMP
GLYCOL SURGE TANK
CRYSTALLIZER CIRCULATION PUMP
TREATED PURGE PUMP
CENTRATE TANK
L.P. STEAM
CONDENSATE
PURGE SOLIDS DRYER
PURGE SOLIDS ELEVATOR
PURGE SOLIDS BIN

Figure 3-5. Wellman-Lord system.

in the flue gas is removed in the absorber.

The solution is discharged from the base of the absorption section of the tower into a sodium bisulfite storage tank. Use of this tank and the companion sodium sulfite storage tank permits regulation of the feed and provides enough surge capacity to allow the absorber to operate independently of the rest of the process.

From the storage tank, the solution enters an evaporator, where low-pressure steam heats the solution, driving off sulfur dioxide and water vapor. Sodium sulfite is precipitated and a dense slurry of crystals is formed. To reduce the steam requirement, double-effect evaporators are used. The overhead from the first evaporator condenses in the reboiler of the second evaporator. The overheads from the second evaporator and the noncondensable fractions from the first evaporator are passed through a partial condenser. From the partial condenser the sulfur dioxide/water mixture is rectified in a stripper. The overheads from the stripper pass through another partial condenser to remove the aqueous phase. The noncondensables from this condenser, containing about 90 percent sulfur dioxide by weight (10 percent water vapor), are further processed to recover sulfuric acid, elemental sulfur, or liquid SO_2. Condensate from the reboiler, the stripper bottoms, and fresh make-up water are used to redissolve the sodium sulfite crystals in a dissolving tank. The solution, primarily sodium sulfite, is pumped from the dissolving tank to the sulfite storage tank.

To prevent buildup of sodium sulfate and other inert materials such as fly ash, some of the liquid leaving the abosrber is purged from the system. This purge stream is chilled to precipitate the sodium sulfate crystals. The crystals and fly ash are separated with a centrifuge, then washed and dried. The treated purge stream is recycled to the system. Caustic soda or soda ash is added to replenish the sodium ion lost from the system in the purge stream.

Capital and annualized model plant costs for the Wellman-Lord system are shown in Table 3-6.

3.2 FACTORS AFFECTING FGD PROCESS SELECTION

Several factors have major impact on selection of an FGD process for a given set of site specific conditions. These factors include sulfur removal requirements, land availability, sludge disposal, by-product markets, flue gas volume, availability of raw materials, availability of steam and natural gas, and utility costs.

The quantity of SO_2 to be removed at an FGD installation is dictated by the difference between the SO_2 emission rate, which varies directly with the sulfur content of the fuels, and the emission rate allowed by the applicable regulation. The SO_2 removal requirements affect the size of the facilities for treatment and disposal of sludge produced

Table 3-6. WELLMAN-LORD SCRUBBING COSTS

Model plant characteristics	Capital,		Operating[a] and maintenance, mills/kWh	Annualized Fuel and electricity, mills/kWh	Fixed costs, mills/kWh	Total,	
	$/kW	$ MM				mills/kWh	$ MM
250 megawatt capacity							
Retrofit, 3.5% S	99.73	24.93	1.743	0.881	3.160	5.783	7.599
New, 3.5% S	86.07	21.52	1.562	0.881	2.727	5.170	6.793
Retrofit, 0.6% S	74.66	18.67	1.408	0.787	2.365	4.560	5.992
New, 0.6% S	62.36	15.59	1.247	0.787	1.975	4.009	5.268
500 megawatt capacity							
Retrofit, 3.5% S	91.54	45.77	1.424	0.871	2.902	5.196	13.655
New, 3.5% S	82.49	41.25	1.304	0.871	2.613	4.788	12.583
Retrofit, 0.6% S	67.79	33.90	1.105	0.778	2.148	4.031	10.593
New, 0.6% S	59.06	29.53	0.990	0.778	1.871	3.639	9.563
1000 megawatt capacity							
Retrofit, 3.5% S	85.47	85.47	1.236	0.857	2.709	4.802	25.239
New, 3.5% S	78.42	78.42	1.143	0.857	2.484	4.484	23.568
Retrofit, 0.6% S	63.74	63.74	0.945	0.773	2.019	3.737	19.642
New, 0.6% S	57.07	57.07	0.857	0.773	1.808	3.438	18.070

[a] No credits included.

in nonregenerative systems. The effect of SO_2 removal requirements on capital cost is illustrated in Figure 3-6, which shows the differential for a model 500 MW existing plant over a range of coal sulfur contents (allowable SO_2 emission rate of 1.2 lb/MM Btu). As the figure shows, costs of the Wellman-Lord system are much more sensitive to SO_2 removal requirements than are costs of the other systems.

Land availability, sludge disposal, and by-product markets are interrelated. Abundance of land reduces sludge disposal costs and makes nonregenerable systems somewhat more favorable. Good markets for by-products favor regenerative systems.

High flue gas volumes favor the sodium compound absorbing systems, which have lower pressure drops and L/G ratios. High costs of electricity also favor the sodium compound systems. High costs of steam penalize the Wellman-Lord system. Scarcities of fuel oil and natural gas affect the magnesium oxide system adversely. Table 3-7 summarizes the impacts of different variables on each of the processes.

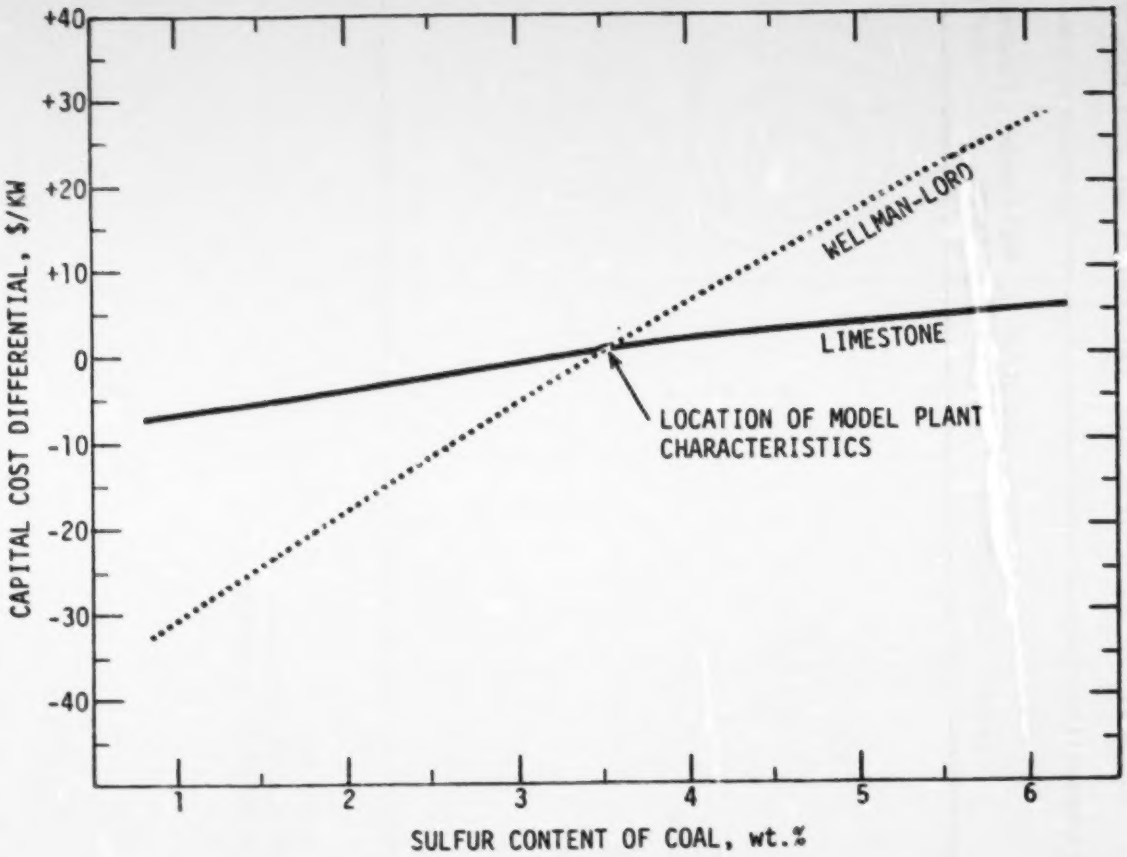

Figure 3-6. Incremental effect of sulfur content of coal on model plant capital Cost (model plant characteristics: 500 MW/existing).

Table 3-7. EFFECTS OF SITE-SPECIFIC VARIABLES ON FGD SYSTEMS

Impact	Lime	Limestone	Double alkali	Wellman-Lord	Magnesium oxide
High utilities			+	+	
No natural gas or oil					-
Scaling	-	-	+	+	+
Sulfur removal	+	+	+	-	
Land availability	-	-	-	+	+
Sludge disposal	-	-	-	+	+
High steam cost				-	
Raw material availability	-	-			
Flue gas volume			+	+	

Key

+	Favors process
-	Does not favor process
Black	Does not affect process

4. SURVEY OF FGD SYSTEM COSTS

A survey of the utility industry was conducted by the Edison Electric Institute (EEI) to determine the costs of FGD systems. EEI contacted all utilities known to have an FGD system that is operational or under construction, or who plan to install such a system. The utilities were asked to complete a 14-page questionnaire, providing information about the system and its costs. Responses encompassed 43 systems. As anticipated, the reported costs cover a broad range; variations are attributable both to site-specific factors and to nonuniformity with respect to items included in the cost estimates.

PEDCo's analysis of the EEI data centers on adjusting the estimates to a common basis to determine representative costs. No attempt is made to verify the costs reported by any utility or to evaluate system design. Adjustments focus primarily on the following items:

- Costs are adjusted to January 1975 dollars. Costs are reported in dollar values ranging from the years 1970 to 1980.
- Costs of particulate control are included. Since the purpose of the study is to estimate the incremental cost for SO_2 control, particulate control costs are deducted either on the basis of

data contained in the cost breakdowns or as a percentage of the total direct equipment cost. The percentage reduction varies with system design.

- Indirect charges are adjusted, usually upward, to provide adequate funds for engineering, field expenses, overheads, interest during construction, start-up, and contingency.
- Replacement power costs are deducted, since only a few utilities report such costs and these are determined by a variety of methods. Thus the adjusted costs do not include replacement power.
- Sludge disposal costs are adjusted to reflect the costs of SO_2 scrubber sludge disposal only (i.e., not disposal of fly ash) and to provide for disposal over the anticipated lifetime of the FGD system. This latter correction is necessary because several utilities report costs for demonstration sludge disposal systems that would last only a fraction of the FGD system life.
- Costs of a regeneration facility and acid or sulfur recovery facility are added for those regenerable systems not reporting such costs.

To the extent possible, all cost adjustements are made on the basis of the cost breakdown data provided on the questionnaire. Where these data are inadequate, costs adjustments are based upon system design parameters. In some cases, no adjustments are possible because of insufficient data; in others, no adjustments are warranted because of unique circumstances (e.g., a demonstration unit with funds included for experimentation).

The adjusted costs for all systems with sufficient data (30 systems), range from \$50 to \$205 kW with an average of \$91/kW (σ = 33.90). Both the upper end of the range and the average costs are high because of an exceptionally high cost reported by the New England Power Company for a prototype FGD system; the utility stated that their reported values should be considered "upper limits." Excluding the costs reported by New England Power Company, the costs range from \$50 to \$137 kW, with an average value of \$85/kW. Adjusted costs for lime- and limestone-based systems reported by 19 utilities range from \$50 to \$88/kW, with an average of \$70/kW ($\sigma = 9.48$). These adjusted costs agree substantially with those developed by use of the cost estimating manuals.

The values reported by individual facilities, the factors considered in the cost adjustments, and the adjusted costs are presented in Table 4-1. Table 4-2 compares estimates derived by use of the cost estimating manuals with the adjusted estimates reported by utilities and manufacturers.

Table 4-1. SUMMARY OF UTILITY INDUSTRY SURVEY

Company Plant Location	Capacity[a] MW	Reported Costs Capital		Comments	1975 Adjusted Costs Capital	
		$ Millions	$/KW		$ Millions	$/KW
Alabama Electric Cooperative Tombigbee Units 2 & 3 Jackson, Alabama Process - Limestone Status - Under Consideration Start-up Date: 3/78, 1/79	357 510	40.464 (1975)	113.34	1. Deleted costs for particulate control	29.047	81.36
Allegheny Power Service Corp. Pleasants Power Station Units 1 & 2 Willow Island, West Virginia Process - Lime Status - Under Consideration Start-up Date: 8/78, 8/79	1236 1236			1. No costs available		
Arizona Public Service Company Cholla Unit 1 Joseph City, Arizona Process - Limestone Status - Operational Start-up Date: 12/73	59.9 119.8	6.55	109.35	1. Adjusted costs from 1973 to 1975 2. Deleted costs for particulate control 3. Adjusted pond life and costs from 2 years to 22 years 4. Added limestone preparation and sludge disposal costs 5. Considered costs for system representative for treating full 119.8 MW; only difference between the modules is that module B is not packed	7.036	58.73
Boston Edison Company Mystic Station Charlestown, Massachusetts Process - Magnesium Oxide Status - Operational Start-up Date: 4/72	150 150	5.01 (Actual Costs)	33.4	1. Added regeneration system costs 2. Added reheat costs 3. Added acid plant costs 4. Increased costs from demonstration unit to permanent installation	17.005	113.37
Central Illinois Public Service Co. Newton Station Unit 1 Newton, Illinois Process - Lime/Limestone Status - Evaluating Bids Start-up Date: 12/77	600 600			1. No costs available; bids being evaluated		

[a] Top number is the FGD system capacity; bottom number is the total capacity of the units to which the FGD system is applied.

Table 4-1 (continued). SUMMARY OF UTILITY INDUSTRY SURVEY

Company Plant Location	Capacity[a] MW	Reported Costs Capital		Comments	1975 Adjusted Costs Capital	
		$ Millions	$/KW		$ Millions	$/KW
Cincinnati Gas & Electric Company Miami Fort Station Unit 8 North Bend, Ohio Process - Lime Status - Planned Start-up Date: 1/78	500 500	40.702 (1978)	81.40	1. Adjusted costs from 1978 to 1975 2. Added sludge disposal and transportation costs 3. Deleted replacement capacity cost	36.616	73.23
Columbus & Southern Ohio Electric Co. Conesville Generating Station Units 5 & 6 Conesville, Ohio Process - Lime Status - Under Construction Start-up Date: 5/75, 5/76	822 822	38.661 (1975)	47.03	1. Added indirect costs 2. Deleted costs for particulate control 3. Adjusted pond life and costs from 5 years to 33 years.	61.563	74.89
Dallas Power & Light Company Texas Electric Service Co. Texas Power & Light Co. Martin Lake Steam Electric Station Units 1, 2, 3, & 4 Rusk County, Texas Process - Limestone Status - Under Construction or Planned Start-up Date: 2/77, 8/77, 12/76, 12/79	1500 (1 & 2) 1500	50.436 (1974)	33.62	1. Adjusted costs from 1977 to 1975 2. Deleted costs for particulate control 3. Added indirect costs 4. Adjusted pond life and costs from 7 years to 35 years 5. Costs are identical for Unit 2; costs given for Units 3 & 4 were incomplete 6. 1500 MW of capacity	75.082	50.12
Dallas Power & Light Company Texas Electric Service Co. Texas Power & Light Co. Monticello Steam Electric Station Unit 3 Titus County, Texas Process - Limestone Status - Planned Start-up Date: 12/78	750 750			1. Costs given were incomplete		

[a] Top number is the FGD system capacity; bottom number is the total capacity of the units to which the FGD system is applied.

Table 4-1 (continued). SUMMARY OF UTILITY INDUSTRY SURVEY

Company Plant Location	Capacity[a] MW	Reported Costs Capital		Comments	1975 Adjusted Costs Capital	
		$ Millions	$/KW		$ Millions	$/KW
Detroit Edison Company St. Clair Power Plant Unit 6 Belle River, Michigan Process - Limestone Status - Under Construction Start-up Date: 5/75	170 325	13.088 (1975)	80.54	1. Increased costs from test module to permanent installation 2. Deleted costs for particulate control 3. Adjusted pond life and costs from 1 year to 20 years 4. Added limestone preparation costs	13.693	80.55
Detroit Edison Company Monroe Units 1, 2, 3, & 4 Monroe County, Michigan Process - Limestone Status - Under Construction Start-up Date: 1981	3000 3000	344.0 (1981)	114.67	1. Adjusted costs from 1981 to 1975 2. Detailed cost breakdown was not available	262.6	87.53
Duquesne Light Company Frank R. Phillips Station Units 1, 2, 3, 4, 5, & 6 Wireton, Pennsylvania Process - Lime Status - Operational Start-up Date: 1973	138.3 414.9	32.346 (1974)	77.96	1. Adjusted costs from 1974 to 1975 2. Deleted costs for particulate control 3. Adjusted pond life and costs from 3 years to 20 years	10.456	75.60
General Public Utilities Service Corp. (Penna. Electric Co. & N.Y. State Electric & Gas Company) Homer City Station Unit 3 Homer City, Pennsylvania Process - Lime Status - Planned Start-up Date: 10/77	650 650	60.192 (1977)	92.60	1. Adjusted costs from 1977 to 1975 2. Decreased costs for 25% system redundancy 3. Added interest costs 4. Added contingency and start-up costs 5. Deleted replacement power costs	47.750	73.46
Illinois Power Company Wood River Unit 1 East Alton, Illinois Process - Catalytic Oxidation Status - Operational Start-up Date: 8/74	103 103	8.2957 (1975)	80.54	1. Adjusted costs from 1970 to 1975 2. Added interest costs 3. Electrostatic precipitator costs allowed since the system requires essentially ash free flue gas	10.649	103.39

[a] Top number is the FGD system capacity; bottom number is the total capacity of the units to which the FGD system is applied.

Table 4-1 (continued). SUMMARY OF UTILITY INDUSTRY SURVEY

Company Plant Location	Capacity[a] MW	Reported Costs Capital		Comments	1975 Adjusted Costs Capital	
		$ Millions	$/KW		$ Millions	$/KW
Indianapolis Power & Light Co. Petersburg Generating Station Unit 3 Petersburg, Indiana Process - Limestone Status - Planned Start-up Date: 4/77	532 532	32.856 (1974)	61.76	1. Adjusted costs from 1974 to 1975 2. Deleted costs for particulate control 3. Increased contingency 4. Added sludge disposal costs	39.120	73.53
Kansas Power & Light Co. Lawrence 4 & 5 Lawrence, Kansas Process - Limestone Injection Status - Operational Start-up Date: 1/68, 6/71	525 525			1. No costs available		
Kentucky Utilities Company Green River Power Station Units 1, 2, & 3 Central City, Kentucky Process - Lime Status - Under Construction Start-up Date: 5/75	60 60	3.966 (1975)	66.10	1. Turnkey contract costs reported 2. Insufficient cost breakdown to permit cost adjustments	3.966	66.10
Montana Power Company Colstrip Units 1 & 2 Colstrip, Montana Process - Lime Status - Under Construction Start-up Date: 7/75, 5/76	716 716	65.266 (1975)	91.15	1. Deleted costs for particulate control 2. Added sludge disposal costs - pond and equipment.	51.990	72.61
New England Power Company Brayton Point Unit 1 Somerset, Massachusetts Process - Metal Oxide Status - Under Construction Start-up Date: 1/77	75 250	14.811 (1975)	197.48	1. Added start-up costs 2. Demonstration unit; costs not representative of full scale system	15.341	204.55

[a] Top number is the FGD system capacity; bottom number is the total capacity of the units to which the FGD system is applied.

Table 4-1 (continued). SUMMARY OF UTILITY INDUSTRY SURVEY

Company Plant Location	Capacity[a] MW	Reported Costs Capital		Comments	1975 Adjusted Costs Capital	
		$ Millions	$/KW		$ Millions	$/KW
New England Power Company Brayton Point Unit 3 Somerset, Massachusetts Process - Metal Oxide Status - Under Construction Start-up Date:	654 654	95.0 (1975)	145.26	1. Added start-up costs 2. Utility states that these costs reported should be considered the upper limit	98.4	150.46
Northern Indiana Public Service Co. Dean H. Mitchell Plant Unit 11 Gary, Indiana Process - **Wellman/Allied** Status - Under Construction Start-up Date: **4/76**	115 115	13.441 (1975)	116.88	1. Wellman-Lord system with Allied Sulfur recovery process 2. Insufficient cost breakdown to permit cost adjustments.	13.441	116.88
Northern States Power Company Sherburne County Generating Plant Units 1 & 2 Becker, Minnesota Process - Limestone Status - Under Construction Start-up Date: 5/76, 5/77	1360 1360	60.0 (1975)	44.12	1. Added indirect costs 2. Decreased costs for 9% system redundancy 3. Adjusted pond life and costs from 12 years to 30 years 4. Increased sludge disposal costs 5. Available cost breakdown insufficient to permit proper adjustments	95.689	70.36
Ohio Edison Company Bruce Mansfield Plant Units 1 & 2 Shippingport, Pennsylvania Process - Lime Status - Under Construction Start-up Date: 12/75, 4/77	1834 1834	213.2 (1977)	116.25	1. Adjusted costs from 1977 to 1975 2. Deleted costs for particulate removal 3. Decreased costs to remove approximately 20% system redundancy 4. Reduced pond cost to account for SO_2 control only. Original pond & sludge transport treatment system cost was 42% of total direct capital cost compared to typically reported values of 10 - 15%	142.699	77.81
Philadelphia Electric Company Eddystone Generating Station Unit 1 Chester, Pennsylvania Process - Magnesium Oxide Status - Under Construction Start-up Date: 6/75	103.3 325	20.189	186.42	1. Adjusted costs from 1972 to 1975 2. Deleted costs for particulate removal 3. Added interest 4. Added acid plant & ancillaries	14.837	137.00

[a] Top number is the FGD system capacity; bottom number is the total capacity of the units to which the FGD system is applied.

Table 4-1 (continued). SUMMARY OF UTILITY INDUSTRY SURVEY

Company Plant Location	Capacity[a] MW	Reported Costs Capital		Comments	1975 Adjusted Costs Capital	
		$ Millions	$/KW		$ Millions	$/KW
Potomac Electric Power Company Dickerson Unit 3 Dickerson, Maryland Process - Magnesium Oxide Status - Operational Start-up Date: 9/73	95 184	6.500 (1973)	68.42	1. Adjusted costs from test module to permanent installation 2. Adjusted costs from 1973 to 1975 3. Added interest costs 4. Added regeneration and acid plant costs	13.68	144.00
Public Service of New Mexico San Juan Station Unit 1 Waterflow, New Mexico Process - **Wellman/Allied** Status - Planned Start-up Date: 12/76	350 350	44.755 (1974)	127.87	1. Adjusted costs from 1976 to 1975 2. Decreased costs for 33% system redundancy 3. Deleted particulate removal costs 4. Chemical plant 100% oversized: no cost adjustment made	39.348	112.42
Public Service of New Mexico San Juan Station Unit 2 Waterflow, New Mexico Process - **Wellman/Allied** Status - Planned Start-up Date: 6/77	350 350	44.755 (1974)	127.87	1. Adjusted costs from 1977 to 1975 2. Decreased costs from 33% system redundancy 3. Deleted particulate removal costs 4. Chemical plant 100% oversized; no cost adjustment made	39.348	112.42
Public Service of New Mexico San Juan Station Unit 3 Waterflow, New Mexico Process - **Wellman/Allied** Status - Under Consideration Start-up Date: 5/78	550 550	59.199 (1974)	107.63	1. Adjusted costs from 1978 to 1975 2. Decreased costs for 25% system redundancy 3. Deleted particulate removal costs 4. Chemical plant 100% oversized; no cost adjustment made	52.431	95.33
Public Service of New Mexico San Juan Station Unit 4 Waterflow, New Mexico Process - **Wellman/Allied** Status - Under Consideration Start-up Date: 5/80	550 550	71.137 (1980)	129.34	1. Adjusted costs from 1980 to 1975 2. Decreased costs for 25% system redundancy 3. Deleted particulate removal costs 4. Chemical plant 100% oversized; no cost adjustment made	52.431	95.33

[a] Top number is the FGD system capacity; bottom number is the total capacity of the units to which the FGD system is applied.

Table 4-1 (continued). SUMMARY OF UTILITY INDUSTRY SURVEY

Company Plant Location	Capacity[a] MW	Reported Costs Capital		Comments	1975 Adjusted Costs Capital	
		$ Millions	$/KW		$ Millions	$/KW
Salt River Project Navajo Generating Station Units 1, 2 & 3 Process - Lime/Limestone Status - Under Construction Start-up Date:	2250 2250			1. No costs available		
South Carolina Public Service Auth. Winyah Generating Station Unit 2 Georgetown, South Carolina Process - Limestone Status - Planned Start-up Date: 5/77	140 280	6.819 (1975)	48.71	1. Deleted costs for particulate removal 2. Added interest costs 3. Added sludge disposal costs 4. Added utilities & services costs	7.756	55.40
South Mississippi Elec. Power Ass. R. D. Morrow Sr. Generating Plant Purvis, Mississippi Process - Limestone Status - Planned Start-up Date: 6/77	275.28 444			1. No costs available		
Southern California Edison Company Mohave Generating Station Unit 2 South Point, Nevada Process - Lime Status - Operational Start-up Date: 1/74	169.85 790	7.80 (1975)	45.92	1. Demonstration program. Unable to separate costs or make accurate cost adjustments		
Southern California Edison Company Mohave Generating Station Unit 1 South Point, Nevada Process - Limestone Status - Operational Start-up Date: 10/74	169.85 790	17.1 (10/74)	100.68	1. Demonstration program. Unable to separate costs or make accurate cost adjustments		
Southern California Edison Company Highgrove Generating Station Colton, California Process - Lime Status - Operational Start-up Date: 1/73	10 45	0.400 (1973)	40.00	1. Demonstration program. Unable to separate costs or make accurate cost adjustments		

[a] Top number is the FGD system capacity; bottom number is the total capacity of the units to which the FGD system is applied.

Table 4-1 (continued). SUMMARY OF UTILITY INDUSTRY SURVEY

Company Plant Location	Capacity[a] MW	Reported Costs Capital $ Millions	 $/KW	Comments	1975 Adjusted Costs Capital $ Millions	 $/KW
Southern California Edison Company Mohave Generating Station Units 1 & 2 South Point, Nevada Process - Lime Status - Planned Start-up Date: 6/77	1580 1580	129.0 (1977)	81.65	1. Adjusted costs from 1977 to 1975 2. Deleted costs for particulate removal 3. Decreased costs for 25% system redundancy 4. Added sludge pond costs 5. Adjusted sludge disposal costs	94.891	60.06
Southern California Edison Company Kaiparowits Generating Station Units 1, 2, 3 & 4 Page, Arizona Process - Lime Status - Under Consideration Start-up Date: 1980	3000 3000	300 (1980)	100.00	1. Adjusted costs from 1980 to 1975 2. No cost breakdown available to permit proper adjustments	189.05	63.02
Tennessee Valley Authority Widows Creek Steam Plant Unit 8 Stevenson, Alabama Process - Limestone Status - Under Construction Start-up Date: 2/77	550 550	55.636 (1977)	101.16	1. Adjusted costs from 1977 to 1975 2. Deleted costs for particulate removal 3. Increased sludge disposal costs	37.681	68.51
Virginia Electric & Power Company Mt. Storm Mt. Storm, Virginia Process - Limestone Status - Under Construction Start-up Date: 12/77	1147.11 1662.48	85.739 (1978)	74.74	1. Adjusted costs from 1977 to 1975 2. Increased indirect costs 3. Added sludge disposal costs for SO_2 disposal for 23 years 4. Deleted coal refuse from sludge disposal costs	84.873	73.99

[a] Top number is the FGD system capacity; bottom number is the total capacity of the units to which the FGD system is applied.

Table 4-2. RANGES OF COSTS REPORTED FOR FLUE GAS DESULFURIZATION SYSTEMS

FGD Process	Manufacturers		PEDCo[a]		Utility industry			
					As reported		Adjusted	
	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit
Regenerable	b	b	57-86	63-99	107[c]	33-197	95[c]	115-205
Nonregenerable (lime/limestone)	33-74	42-78	49-77	55-91	33-129	40-115	50-81	59-87

[a] Values obtained by use of PEDCo's cost-estimating manuals

[b] No costs were available from manufacturers.

[c] Only one plant reported in this category.

5. USE OF THE COST ESTIMATING MANUALS

The cost estimation manuals incorporate nomographs to simplify preparation of cost estimates. Although the cost values also can be developed by use of equations, the nomographs are presented as a rapid and accurate means of preparing the estimate. With these manuals a person proficient in the use of nomographs can generate a site-specific cost estimate in about 4 hours. For applications that involve constraints on time and labor, simplified cost estimation procedures are also presented for each of the FGD systems. By use of these greatly abbreviated procedures, an estimate may be completed in about half an hour.

The following sections describe the input materials required for use of the cost estimation manuals.

5.1 PLANT DATA

Basic information concerning plant operations may be compiled on a survey form. Table 5-1 illustrates a completed plant survey form. Most of the information on this form can be obtained from FPC Form 67. Note that values for generating capacity, fuel usage, and flue gas volume should be at maximum continuous operation. Operating data are to

Table 5-1. PLANT SURVEY FORM

Boiler No.	1	2	3	4
Type of furnace	Pulverized	Cyclone	Cyclone	Pulverized
MW at maximum continuous	75	150	150	500
Age of unit, years	20	15	15	3
Life, years remaining	13	18	18	30
Capacity factor, yr. 74	45	60	60	70
Maximum continuous fuel, ton/hr or gal/min	30.8	61.6	61.6	205.36
Maximum continuous, MM Btu/hr	690	1380	1380	4600
acfm at 310°F	238125	476250	476250	1.54x10^6
Fly ash/total ash, %	85	10	10	85
Efficiency of existing particulate control	85	95	95	99

Cost of electricity/KWH (Plant) = $ 0.02 . Cost of water/M gas. (Plant = $0.20/M gal

Coal, cost/ton $ 25.00

% sulfur by weight 3.5

% ash by weight 11.2

HHV, BTU/lb 11,200

Oil, cost/bbl $ N.A.

% sulfur by weight N.A.

BTU/gal N.A.

Specific gravity N.A.

SO_2 permissible 1.5 lb SO_2/MM Btu

Fly ash permissible 0.12 lb fly ash/MM Btu

State or Federal regulations

Table 5-1 (Continued). PLANT SURVEY FORM

Estimated land cost per acre (current) $ 2000

Possible interference determining the location of flue gas desulfurization (FGD) system:

Congestion between stack and plant [✓ Yes] No

Congestion between stack and/or plant with property line, coal pile, etc. Yes No

Identify problem areas and location: Generation yard is directly behind stacks.

Terrain Open site for placing auxiliary systems.

Conduits Conduits are on the opposite side of the boilers from the stack.

Possible obstructions Although stacks are on the ground, the transmission yard will cause long ducts to open areas at each end of the building.

Source of $CaCO_3$ available Martin-Marietta

and % purity 95

be used in preference to design data; use of both can lead to erroneous results.

5.2 RETROFIT INFORMATION

Application of FGD systems to existing plants usually entails higher costs than those for application to similar new plants. Whereas an FGD system for a new plant can be incorporated into the overall plant design, retrofitting requires that the system be adapted to the given plant configurations; space is usually limited, and ongoing plant operations further constrain installation of the system.

Configuration of equipment in the plant governs the location of the FGD system. For instance, if the boiler stack is on the roof of the boiler house, as it is in many older plants, the FGD system may have to be placed at ground level; this placement could entail long ducting runs from the absorber to the stack or could require construction of a new stack. At some plants the stack is situated directly adjacent to the boiler house or particulate control device, a placement that often necessitates locating the FGD system at some distance, even hundreds of feet away. At some plants, especially those located in urban areas, the available space at ground level is inadequate to accommodate the entire FGD system. In such cases either the FGD scrubber units must be stacked, one on top of the other, or additional land must be acquired adjacent to the plant property.

Terrain of the power plant site also affects the capital cost of the FGD system by sitework and structural requirements. Hilly terrain requires considerable grading and filling to prepare the site for construction of foundations and possible additional structural components. Subsurface conditons can necessitate piling to provide adequate support for the concrete foundations of the FGD system.

Other capital cost components that can be increased because of space restrictions are construction labor and expenses, interest charges during construction (because of longer construction periods), contractor fees and expenses, and allowances for shakedown. Table 5-2 summarizes the capital cost impacts of several retrofit requirements.

Table 5-2. TYPICAL INCREASED IN CAPITAL COSTS WITH VARIOUS RETROFIT REQUIREMENTS

Retrofit requirements	Capital cost[a] increase, %
Long duct runs	4 - 7
Tight space	1 - 18
Delayed construction[b] (1 year delay)	5 - 15
Hilly terrain	0 - 10
New stack	6 - 20
Overall	1 - 70

The cost manuals account for retrofit difficulty in the following areas:

1. Conveyors
2. Ducting
3. Overall labor and material factors.

To increase conveyor and ducting, the user estimates the length of ducting and conveyors to the nearest 100 feet. The cost manual uses actual distances in the calculation of ducting and conveyor costs. The overall labor and material factors adjust the costs for easy, moderate, and difficult retrofits. In general, an easy retrofit entails ample space around the stack and open areas for the auxiliary processes (limestone preparation, sludge processing). In moderate retrofit, either the conduits or transmission yard block access to the stacks, stacks are roof-mounted, or areas for auxiliary processes are limited. In a difficult retrofit, areas for the auxiliary processes are limited and access to the stacks is limited or stacks are roof-mounted.

5.3 UPDATING COST ESTIMATES

The manuals are based on December 1973 cost data. Since that time, costs have escalated greatly. Figure 5-1 shows a cost escalation curve. In updating the cost estimates the equipment costs derived from the manual are multiplied by a factor from the cost escalation curve. For

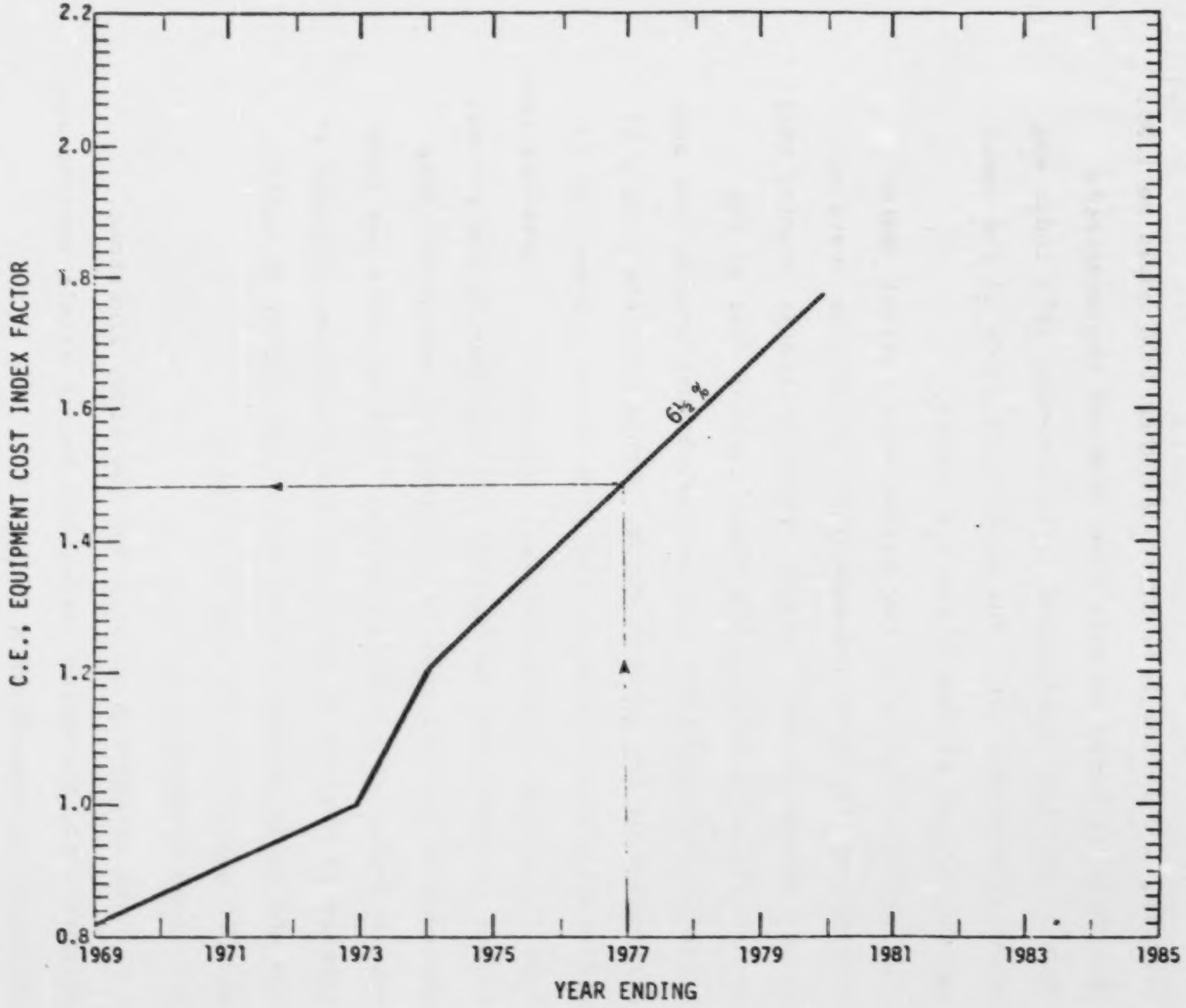

Figure 5-1. Cost escalation curve.

example, the factor for use in December 1970 would be 1.30. The curve is based on data from Chemical Engineering's (C.E.) equipment cost index. The December 1973 index was adjusted to equal 1.0. The escalation curve in the manual can be updated by use of the C.E. index.

Installation of an FGD system from initial design through construction and subsequent acceptance tests requires approximately 3 years. Price escalation during this period directly affects the total capital cost of the project; consequently, cost estimates must account for some percentage of increase in costs. Since progress occurs at different rates throughout the life of the project, so too does the outlay of expenditures. Figure 5-2 illustrates the effect of escalation on capital cost by showing the percent increase of capital cost for a range of escalation rates over a 3-year construction period. The expenditures rate assumes 14 percent of the total installed cost expended at the end of 14 months, 24 percent at the end of 20 months, and 100 percent at the end of 3 years.

5.4 COST ESTIMATION MANUALS

Cost estimation manuals for the lime, limestone, Wellman-Lord, magnesium oxide, and double alkali systems are presented in Appendices A through E.

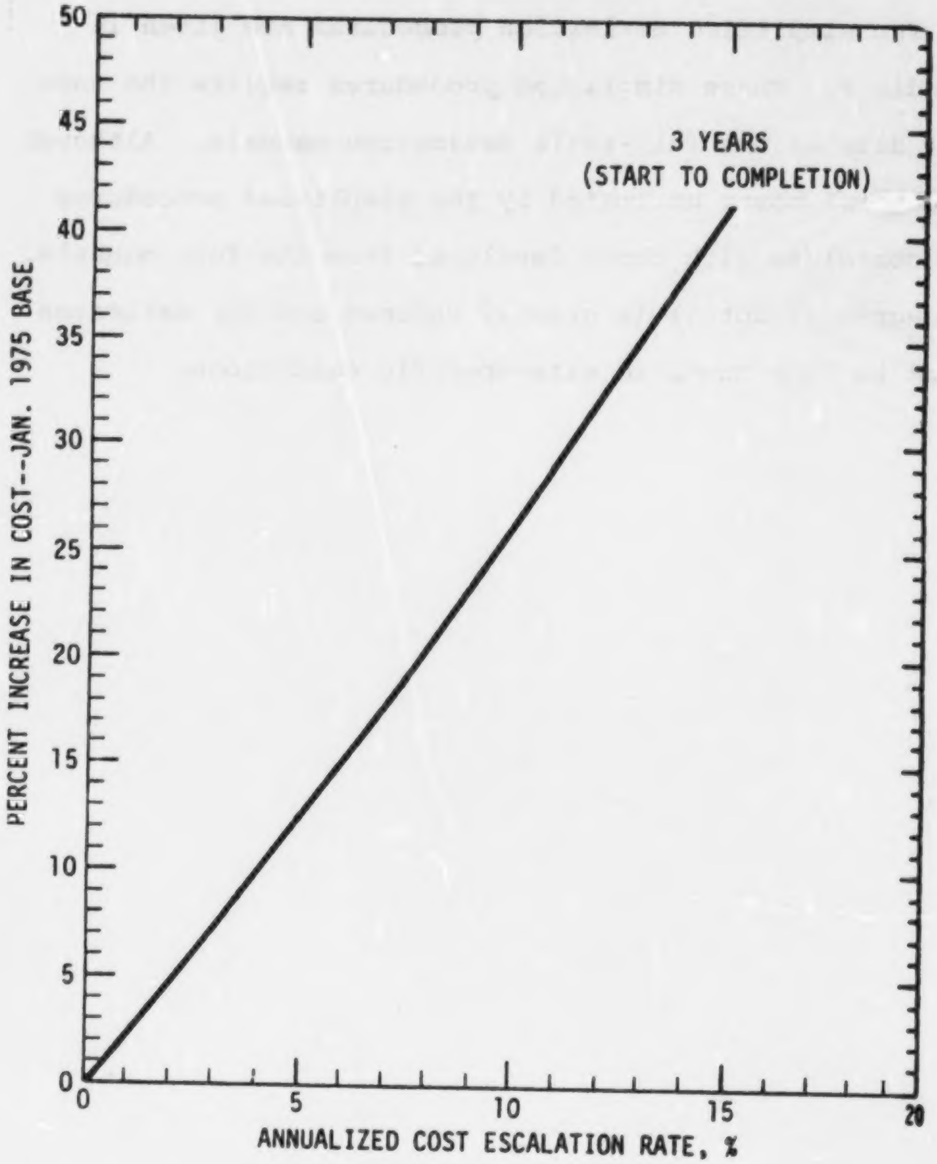

Figure 5-2. Impact of cost escalation.

The simplified estimation procedures are given in Appendix F. These simplified procedures require the same input data as the full-scale estimation manuals. Although the capital costs estimated by the simplified procedures will correlate with those developed from the full manuals, the degree of detail is greatly reduced and the estimates cannot be fine-tuned to site-specific conditions.

APPENDIX A

LIME SCRUBBING

NOTE: For purposes of clarity and continuity, Tables and Charts have been numbered sequentially in this report with no differentiation between Tables and Charts.

INFORMATION REQUIRED

Boiler No.						
Type of furnace						
MW at maximum continuous						
Age of unit, years						
Life, years remaining						
Capacity factor, yr.____						
Maximum continuous fuel, ton/hr or gal/min						
Maximum continuous, MM BTU/hr						
acfm at ____°F						
Fly ash/total ash, %						
Efficiency of existing particulate control, %						

Cost of electricity/KW (Plant) = $______. Cost of water/M gal (Plant) = $_________

Coal, cost/ton $__________

% sulfur by weight __________

% ash by weight __________

HHV, BTU/lb __________

Oil, cost/bbl __________

% sulfur by weight __________

BTU/gal __________

Specific gravity __________

SO_2 permissible __________ lb SO_2/MM BTU

Fly ash permissible __________ lb fly ash/MM BTU

State or
Federal regulations

INFORMATION REQUIRED (continued)

Estimated land cost per acre (current) $____________

Possible interference determining the location of flue gas desulferization (FGD) system:

Congestion between stack and plant ☐ Yes ☐ No

Congestion between stack and/or plant with property line, coal pile, etc., ☐ Yes ☐ No

Identify problem areas and location: ____________

Terrain ____________

Conduits ____________

Possible obstructions ____________

Source of CaO available ____________

and % purity ________

SO_2 EMISSION DETERMINATION

To determine the SO_2 emissions (lb/MM BTU) in the flue gas, Chart 1:

Enter % sulfur by weight of fuel (oil or coal) on $\boxed{1}$

Enter heating value of fuel (BTU/lb) on $\boxed{2}$

Connect $\boxed{1}$ and $\boxed{2}$ and extend to $\boxed{3}$ and record and read:

SO_2 emissions (lb/MM BTU) in flue gas ____________ $\boxed{3}$

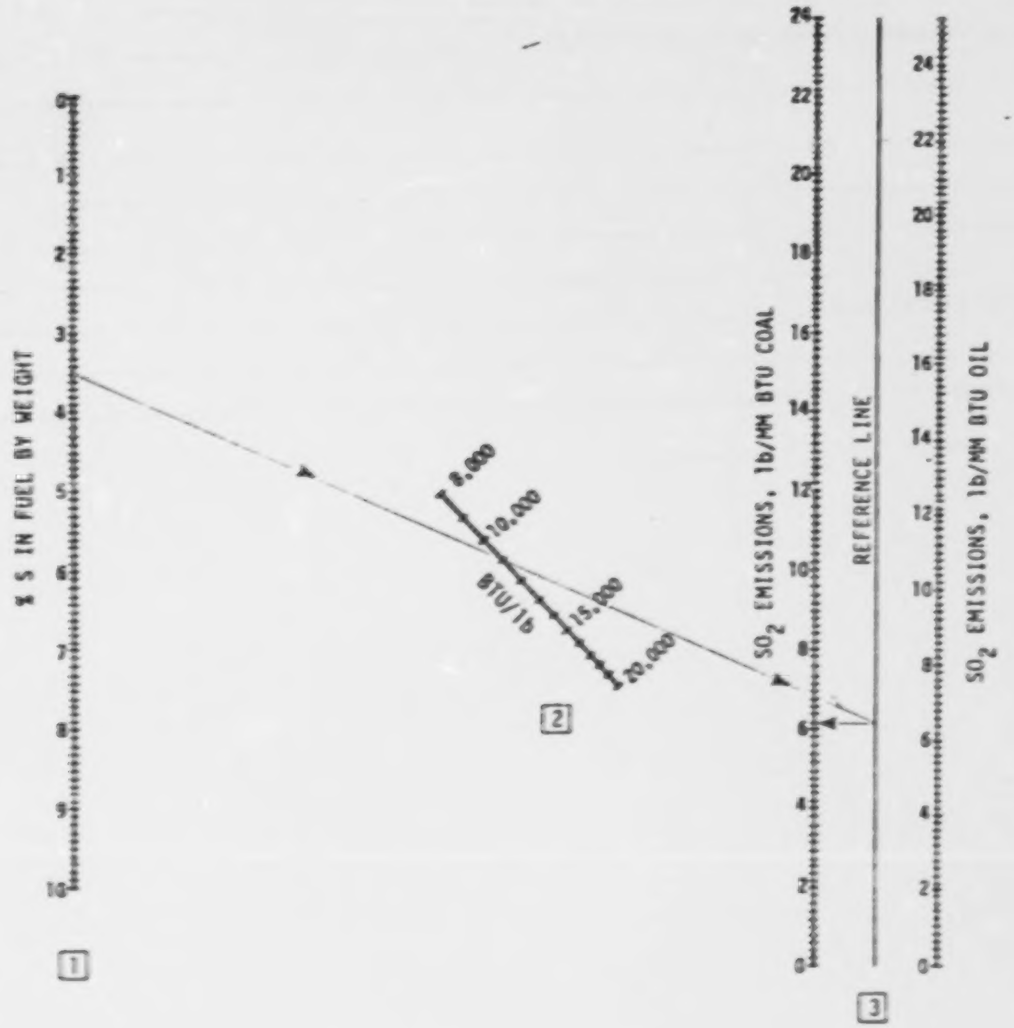

Chart 1. SO_2 EMISSION DETERMINATION

Assumptions:

(1) 95% of sulfur in coal converted to SO_2

(2) 100% of sulfur in oil converted to SO_2

SO_2 REMOVAL REQUIREMENTS

To calculate SO_2 emissions (lb/MM BTU) to be removed:

Enter from page A-4, Chart 1, item $\boxed{3}$ the lb/MM BTU __________ $\boxed{3}$

Enter from the data sheet, allowable SO_2 emissions (lb/MM BTU) from the State or Federal regulations __________ $\boxed{4}$

Subtract $\boxed{4}$ from $\boxed{3}$ to calculate SO_2 emissions (lb/MM BTU) to be removed ______________ $\boxed{5}$

LIME REQUIREMENTS

To determine the lime requirements (lb/hr) Chart 2:

Enter the SO_2 emissions (lb/MM BTU) to be removed on item $\boxed{6}$ from page A-5, item $\boxed{5}$; record ______________ $\boxed{6}$

Enter stoichiometric requirements of lime on item $\boxed{7}$*

Connect $\boxed{6}$ and $\boxed{7}$ and extend to $\boxed{8}$ and read and record:

Lime requirements (lb/MM BTU) _________________ $\boxed{8}$

Record from the data sheets the heat input (MM BTU/hr) _____ $\boxed{9}$

Multiply $\boxed{8}$ times $\boxed{9}$ and record:

Lime requirements (lb/hr) _________________ $\boxed{10}$

Multiply $\boxed{6}$ by $\boxed{9}$ and record: lb SO_2/ hr removed _________________ $\boxed{12}$

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*If unknown, use 1.1.

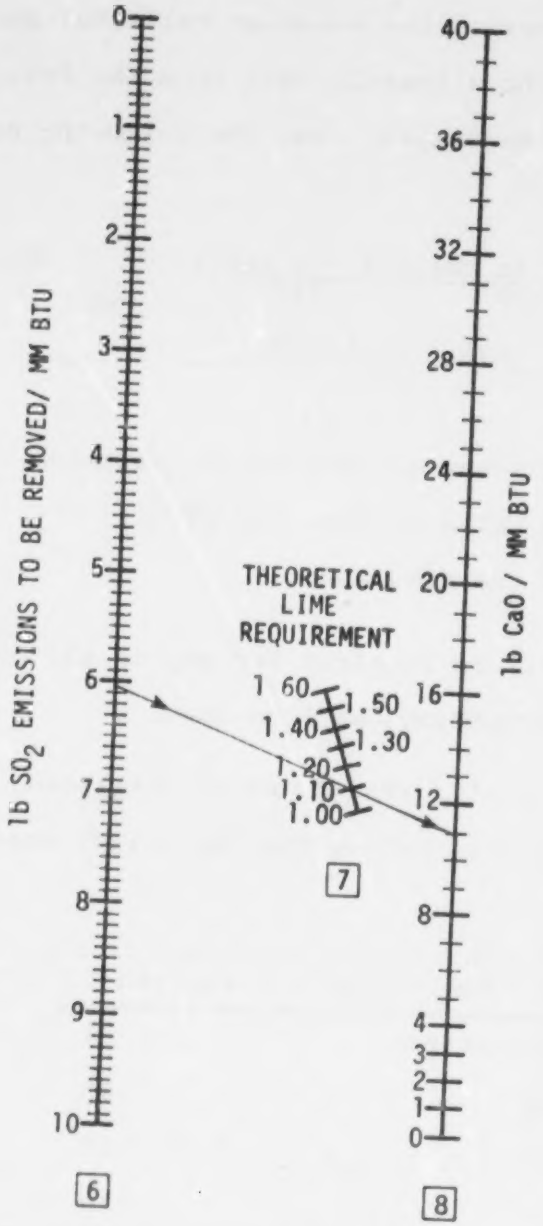


Chart 2. LIME REQUIREMENTS

FLY ASH EMISSION RATE CALCULATIONS FOR VENTURI DETERMINATION

To calculate fly ash emitted:

If the fly ash emitted (lb/MM BTU) in $\boxed{13}$ after passing through an existing particulate emission collector per boiler is greater than the allowable rate from the data sheet, the use of venturi is necessary. Use the following equation to calculate $\boxed{13}$

$$\boxed{13} = \frac{(\%\text{ ash in coal})}{100}\frac{(\%\text{ fly ash*})}{100}\left(1-\frac{\eta_c}{100}\right) \div \text{BTU/lb} \times 10^6 = \text{lb/MM BTU}$$

$$= (0.\_\_\_\_\_)(0.\_\_\_\_\_)(1-0.\_\_\_\_) \div \_\_\_\_\_\_\_\_\_ \times 10^6 = \_\_\_\text{lb/MM BTU}$$

where

$_c$ = Efficiency of particulate emission collector system

BTU/lb = Heat value of fuel (MM BTU/lb)

% ash = from the data sheet

If fly ash removal is required for any or all of the units, VENTURI COST CALCULATIONS will be used.

*If the percent of fly ash to ash is not known, use the appropriate tabulated values for the boiler under consideration.

Type boiler - coal-fired	fly ash to ash, %
General pulverized	80
Dry bottom	85
Wet bottom	65
Cyclone	10

SLUDGE GENERATED

To determine the dry sludge (lb/hr) generated, item 16 , Chart 3:

From page A-8, item $\boxed{13}$ enter the calculation of fly ash (lb/MM BTU) ____________ $\boxed{13}$

From page A-5, item $\boxed{5}$ enter lb SO_2/MM BTU ____________ $\boxed{5}$

From page A-7, Chart 2 item $\boxed{8}$ enter lb CaO/MM BTU

____________ $\boxed{8}$

$\boxed{13} + \boxed{5} + \boxed{8} = \boxed{14}$ total dry sludge (lb/MM BTU)

____________ $\boxed{14}$

From data sheet, heat input maximum continuous rating, record here as (MM BTU/hr) ____________ $\boxed{15}$

Dry Sludge = $\boxed{14}$ x $\boxed{15}$ = $\boxed{16}$ lb/hr

= __________ x __________ = __________ lb/hr $\boxed{16}$

$\boxed{16}$ ÷ 2000 = ______________ ton/hr $\boxed{16}$ A

Wet sludge - Enter $\boxed{16}$ on $\boxed{17}$, Chart 3 and divide by percent weight dry sludge on $\boxed{18}$ = Sludge slurry, lb/hr

$\boxed{17}$ $\boxed{18}$ $\boxed{19}$

= ____________ ÷ 0.6* = ______________ lb/hr $\boxed{19}$ *

*If other than 60 percent by weight is used in determining wet sludge identify ________ %

Enter $\boxed{16}$ on $\boxed{17}$, Chart 3, enter _____ % by weight dry sludge on $\boxed{18}$

Connect $\boxed{17}$ and $\boxed{18}$ and extend to $\boxed{19}$ and read:

Wet Sludge (lb/hr) = ____________ $\boxed{19}$ * C

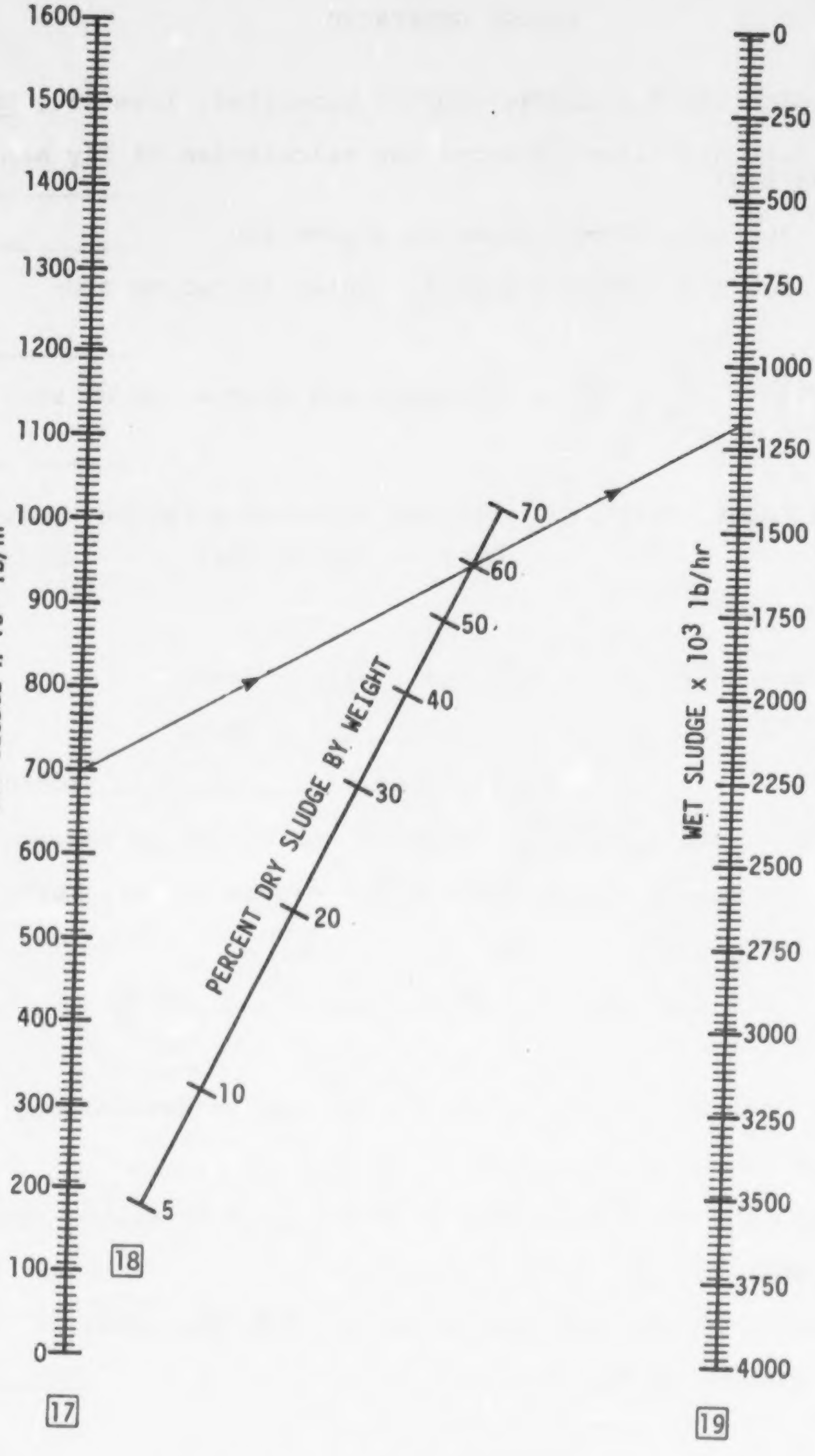


Chart 3. SLUDGE GENERATED

VENTURI AND ABSORBER COSTS

To determine the costs of venturi and absorber (including demister) using lime, Chart 4:

First, determine number of scrubber trains -

Enter acfm at °F of flue gas from the data sheet on $\boxed{20}$, either per boiler or combined plant total if °F is the same for all boilers.

Enter temperature of flue gas (°F) on $\boxed{21}$

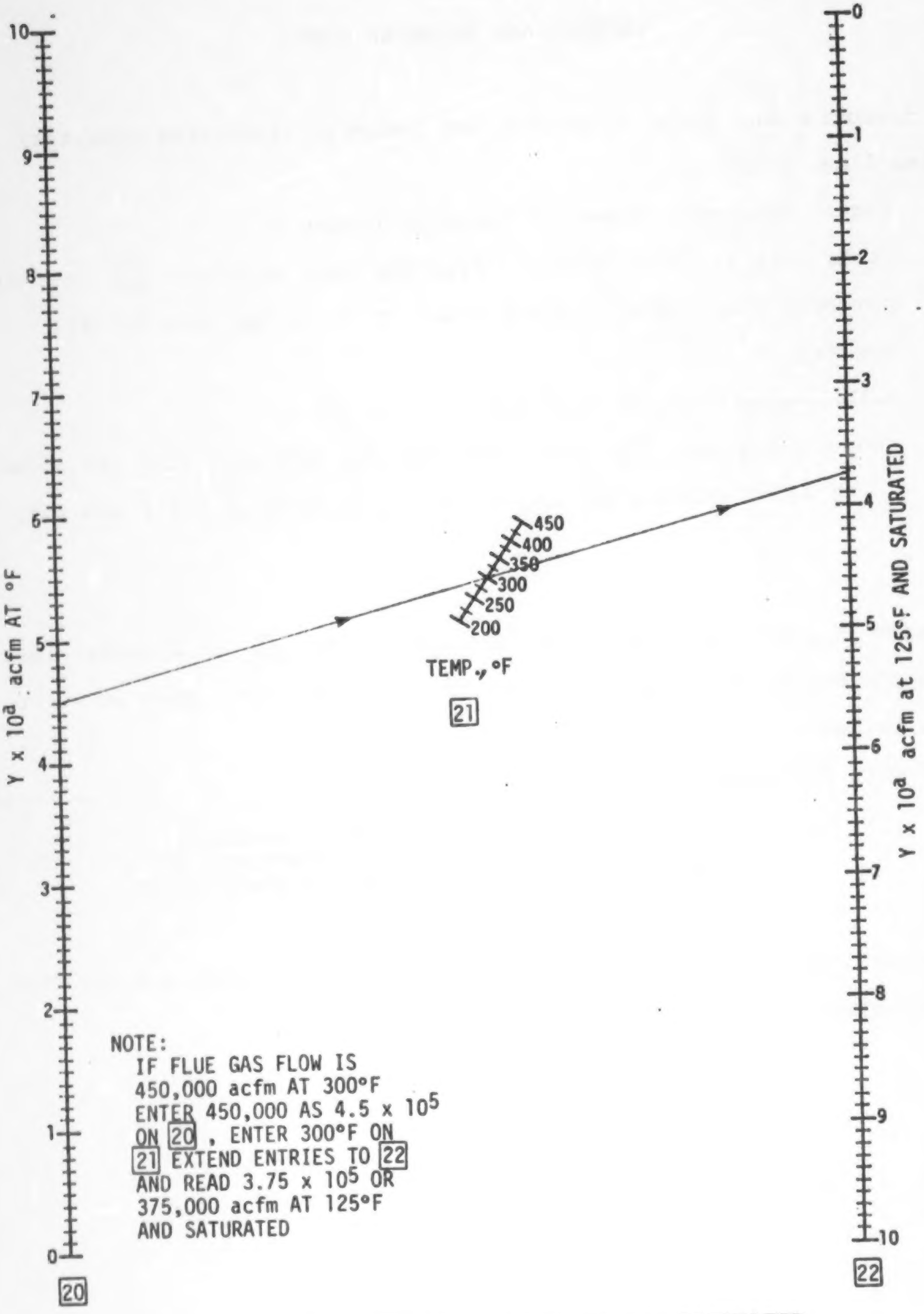
Connect $\boxed{20}$ and $\boxed{21}$ and extend to $\boxed{22}$ and read flue gas acfm at 125°C (saturated) and enter________acfm at 125°F and sat. $\boxed{22}$

If acfm at 125°F is greater than 375,000 divide $\boxed{22}$ by a number less than 375,000 to give a whole number of venturis and/or absorbers for each boiler.

acfm per venturi and/or absorber ____________ $\boxed{23}$

$$\frac{\underline{\hspace{3cm}}\,\boxed{22}}{\boxed{23}} = \underline{\hspace{3cm}}\,\boxed{24}$$ number of venturis and/or absorbers per boiler or power plant.

A venturi, or an absorber, or a combination of a venturi and absorber is sometimes called a train.



NOTE:
IF FLUE GAS FLOW IS
450,000 acfm AT 300°F
ENTER 450,000 AS 4.5 x 10^5
ON 20 , ENTER 300°F ON
21 EXTEND ENTRIES TO 22
AND READ 3.75 x 10^5 OR
375,000 acfm AT 125°F
AND SATURATED

Chart 4. acfm CORRECTED TO 125 °F AND SATURATED

VENTURI AND ABSORBER COSTS

Then determine absorber costs (no venturi required) Chart 5:

Enter item $\boxed{22}$ from page A-12, Chart 4 on Chart 5 on $\boxed{25}$

Enter for the absorber the cost factor of 1.3 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read absorber cost

$ ________________ $\boxed{27}$ A

Or determine venturi and absorber costs (if a venturi is required)

Enter item $\boxed{22}$ from page A-12, Chart 4 on Chart 5 on $\boxed{25}$

Enter the cost factor of 2.2 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read venturi and absorber costs

$ ________________ $\boxed{27}$ V+A

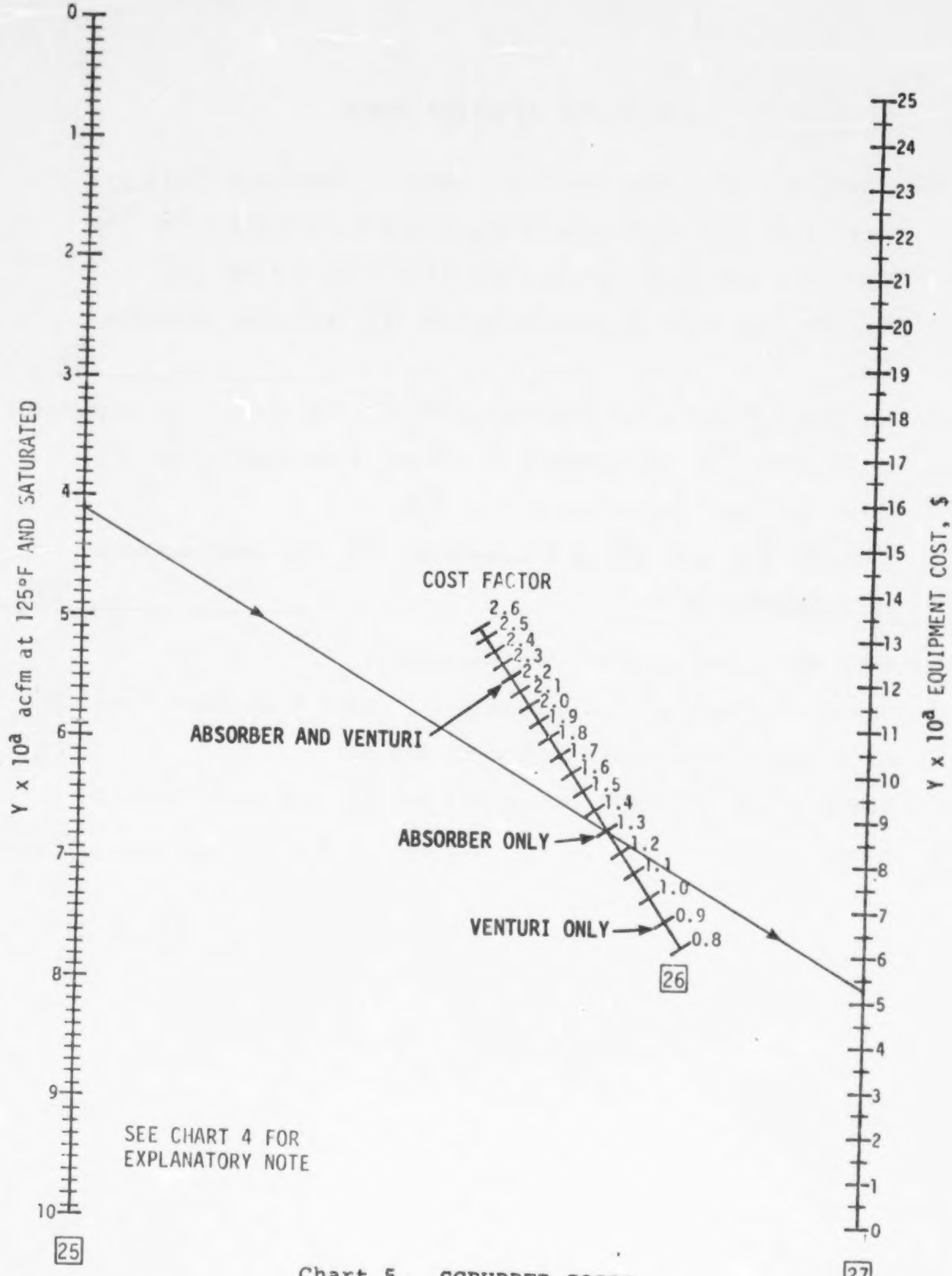
Or determine venturi costs (no absorber):

Now enter item $\boxed{22}$ from page A-12, Chart 4 on Chart 5 on $\boxed{25}$

Enter the venturi cost factor of 0.9 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read venturi costs

$ ________________ $\boxed{27}$ V



SEE CHART 4 FOR
EXPLANATORY NOTE

Chart 5. SCRUBBER COSTS

HOLDING TANK CAPACITY

To determine the holding tank capacity for absorber and/or venturi

Chart 6:

Enter flue gas acfm from page A-12, Chart 4, item $\boxed{23}$ on Chart 6, item $\boxed{29}$

Enter L/G* (liquid flow rate, gpm/1000 acfm at 125°F) on $\boxed{30}$

Connect $\boxed{29}$ and $\boxed{30}$ and extend to $\boxed{31}$, read and record:

Liquid flow rate (gal/min)__________ $\boxed{31}_A$ for absorber

Liquid flow rate (gal/min)__________ $\boxed{31}_V$ for venturi

Enter retention time** on $\boxed{32}$

Connect $\boxed{31}$ and $\boxed{32}$ and extend to $\boxed{33}$, read and record:

Tank capacity (gal) per absorber __________ $\boxed{33}_A$

(gal) per venturi __________ $\boxed{33}_V$

* If unknown, use 40 for absorber and venturi.

** If unknown, use 5 min.

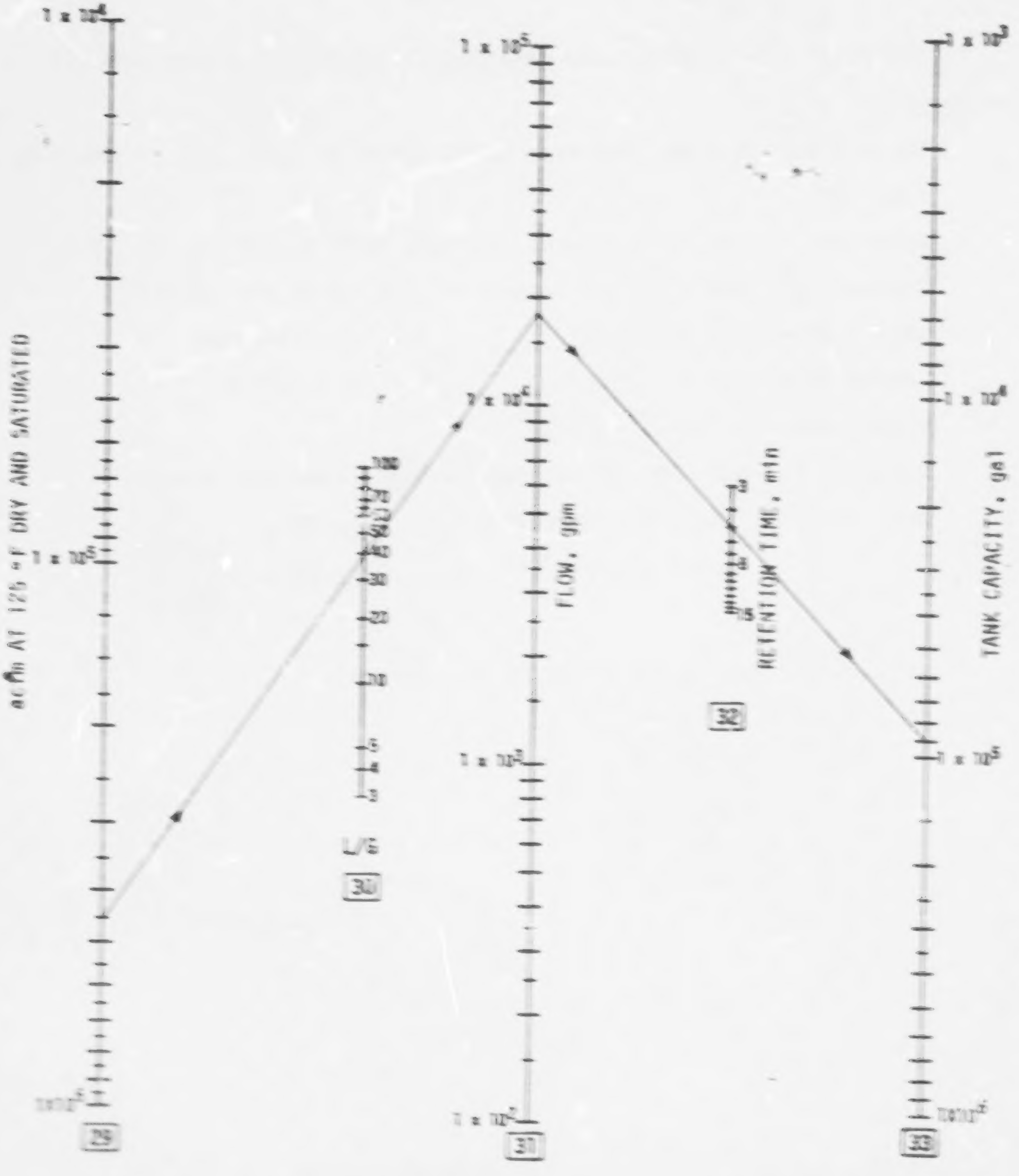


Chart 6. FLOW RATE AND TANK CAPACITY

HOLDING TANK AGITATOR COSTS

To determine the cost of agitators per tank, Table 7:

Compare tank capacity (gallons) from page A-16, Chart 6, item $\boxed{33}_A$ and/or $\boxed{33}_V$ on Table 7 under tank capacity in gallons column and record:

Cost of agitators per tank - absorber $ ______________ $\boxed{34}_A$

venturi $ ______________ $\boxed{34}_V$

Total cost of venturi and/or absorber:

($\boxed{34}_A$ + $\boxed{34}_V$) x No. of venturi or absorbers from item $\boxed{24}$

(____________+__________) x ______________ = $__________ $\boxed{35}$

AGITATOR COST

Table 7. AGITATOR COST

Tank capacity, gal.	Agitators	
	No.	$\boxed{34}_A$ or $\boxed{34}_V$, cost, \$
0 to 34,000	1	2,000
34,000 to 67,000	2	4,000
67,000 to 101,000	3	6,000
101,000 to 135,000	4	8,000
135,000 to 162,000	5	10,000
162,000 to 188,000	6	12,000
188,000 to 220,000	7	14,000
220,000 to 251,000	8	16,000
251,000 to 283,000	9	18,000

HOLDING TANK COSTS

To determine the tank cost the values in the chart are based on using \$12.50/ft^2 for a field-fabricated, rubber-lined tank, Chart 8:

Enter tank capacity (gallons) on $\boxed{36}$ from page A-16, Chart 6.

items $\boxed{33}_A$ and $\boxed{33}_V$, move vertically to $\boxed{37}$

From $\boxed{37}$ move horizontally to $\boxed{38}$, read and record:

Tank cost per absorber \$________________ $\boxed{38}_A$

Cost per venturi \$________________ $\boxed{38}_V$

Total Cost:

($\boxed{38}_A$ + $\boxed{38}_V$) x No. of absorbers $\boxed{24}$ = cost of holding tanks $\boxed{39}$

(__________ + __________) x ____________ = \$______________________ $\boxed{39}$

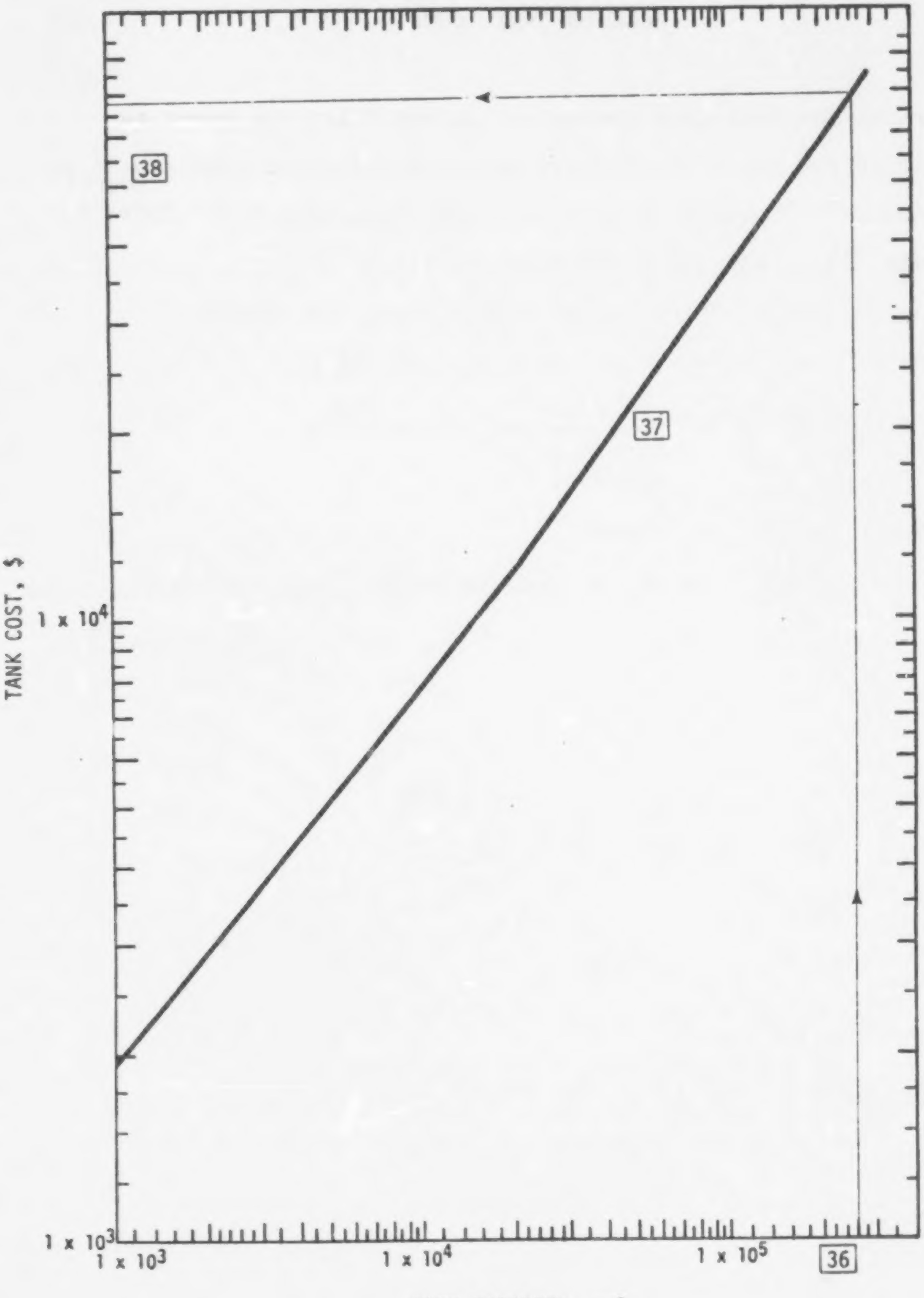


Chart 8. HOLDING TANK COSTS

HOLDING TANK PUMP COSTS

To determine the total pump cost for absorbers and/or venturi, Chart 9:

Enter gpm on $\boxed{40}$ from page A-16, Chart 6, item $\boxed{31}_A$ for the absorber and $\boxed{31}_V$ for the venturi. Select minimum number of pumps on $\boxed{41}$ (note 10,000 gpm per pump*is maximum), use minimum number of pumps per train and add 1 spare pump per tank.

Connect $\boxed{40}$ and $\boxed{41}$ and extend to $\boxed{42}$, read and record:

Flow rate (gpm) per pump ________absorber; __________venturi

Tabulate:	No. of pumps $\boxed{41}$	gpm/pump $\boxed{42}$	No. of trains $\boxed{24}$
Absorber			
Venturi			

For total pump cost for venturi and/or absorber connect $\boxed{42}$ and enter $\boxed{41}$ on $\boxed{43}$ and extend to $\boxed{44}$, read and record:

Pump cost per tank $__________ absorber; $__________venturi

$\boxed{44}_A$ $\boxed{44}_V$

*If gpm per pump is 5,000 or less calculate cost as follows:

Record gpm from page A-16, Chart 6, item $\boxed{31}_A$ for absorber _____$\boxed{45}$

item $\boxed{31}_V$ for venturi ________$\boxed{46}$

Number of trains from page A-11, item 24

Number of pumps per tank 1 + 1 spare

Absorber pump costs:

$$2 \times (\boxed{45}) \times (0.79) \times \boxed{24} = \boxed{47}_A$$

$$1.58 \times (\underline{\qquad\quad}) \times \underline{\qquad\quad} = \$ \underline{\qquad\qquad\qquad} \boxed{47}_A$$

HOLDING TANK PUMP COSTS (Continued).

Venturi pump costs:

$2 \times (\boxed{46}) \times (0.92) \times \boxed{24} = \boxed{47}_V$

$1.84 \times$ (________) $\times$ ______ = \$ ______________ $\boxed{47}_V$

Pump costs, total: from calculation (1 to 5,000 gpm/pump)

$\boxed{47}_V + \boxed{47}_A = \boxed{49}$

______________ + ______________ = \$________________ $\boxed{49}$

Pump costs, total: from Chart 9 (5001 to 10,000 gpm/pump)

$\boxed{44}_V + \boxed{44}_A = \boxed{49}$

______________ + ______________ = \$________________ $\boxed{49}$

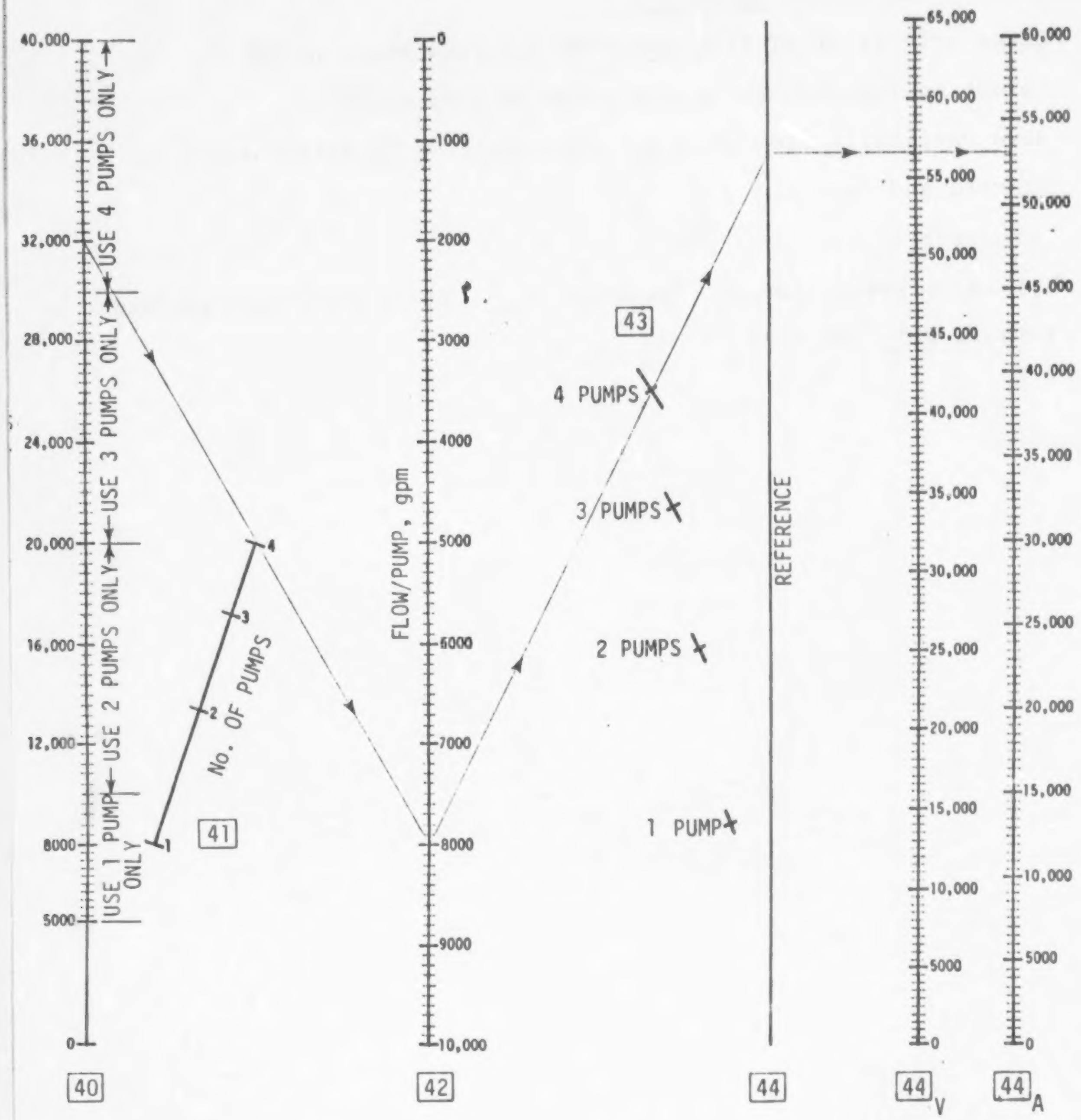


Chart 9. HOLDING TANK VARIABLE PUMP COSTS

FAN COSTS

To determine fan costs, Chart 10:

Enter acfm at °F of flue gas from the data sheet on $\boxed{50}$

Select appropriate curve for pressure drop* on $\boxed{51}$

Move vertically from $\boxed{50}$ to $\boxed{51}$ and then from $\boxed{51}$ horizontally to $\boxed{52}$ read and record:

Fan costs \$__________ $\boxed{52}$

*Typical pressure drops: Absorber 21" (18" + 3"); Absorber and venturi 28" (25" + 3")

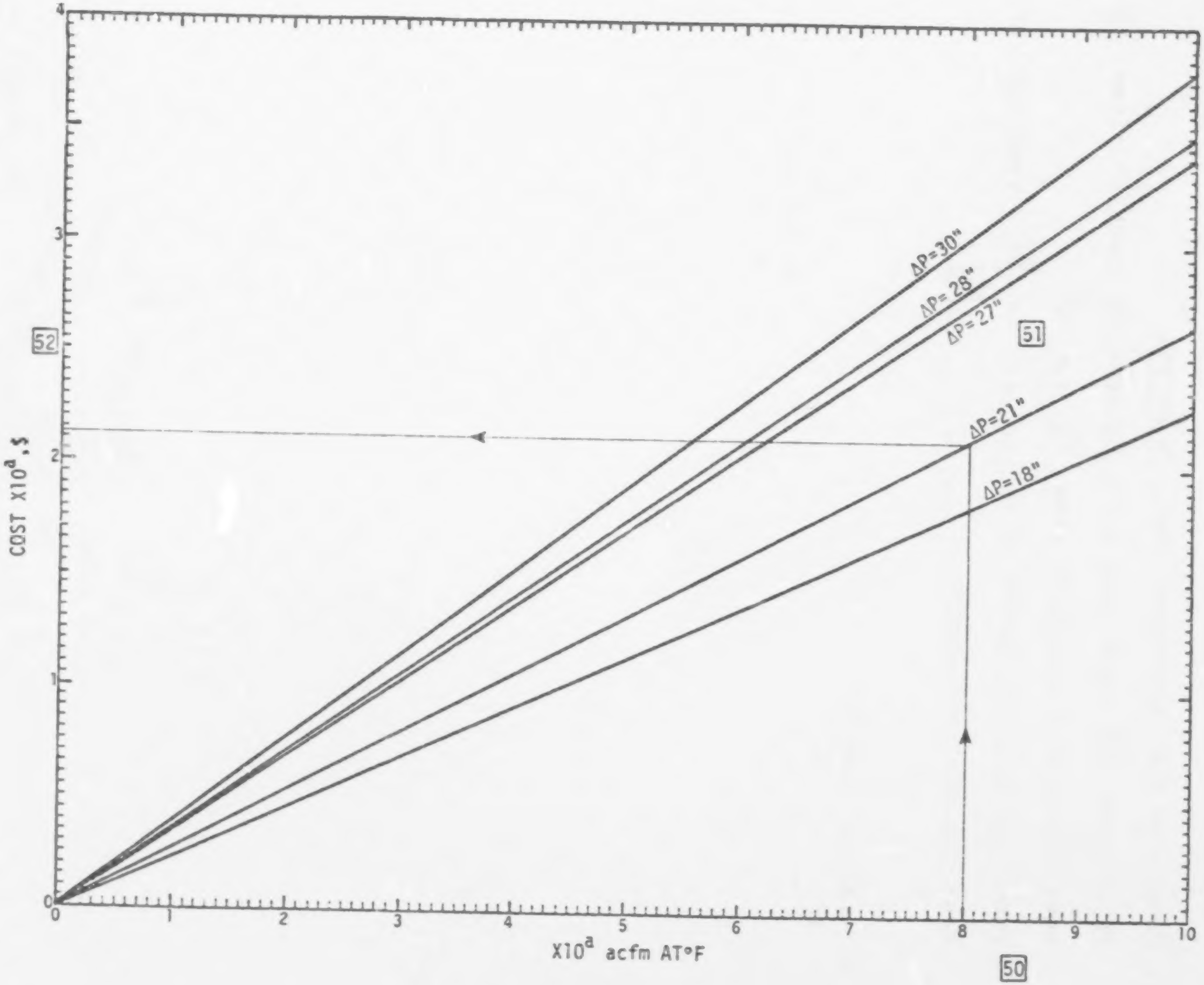


Chart 10. FAN COSTS

HEAT EXCHANGER COST

To determine heat exchanger cost, Chart 11:

Enter item $\boxed{22}$ from page A-12, Chart 4 on Chart 11, item $\boxed{53}$

Move vertically upward to item $\boxed{54}$ for ΔT*

From $\boxed{54}$ move horizontally to the left to $\boxed{55}$, read and record:

Cost for heat exchangers $______________ $\boxed{55}$

---

*If unknown, use 50°.

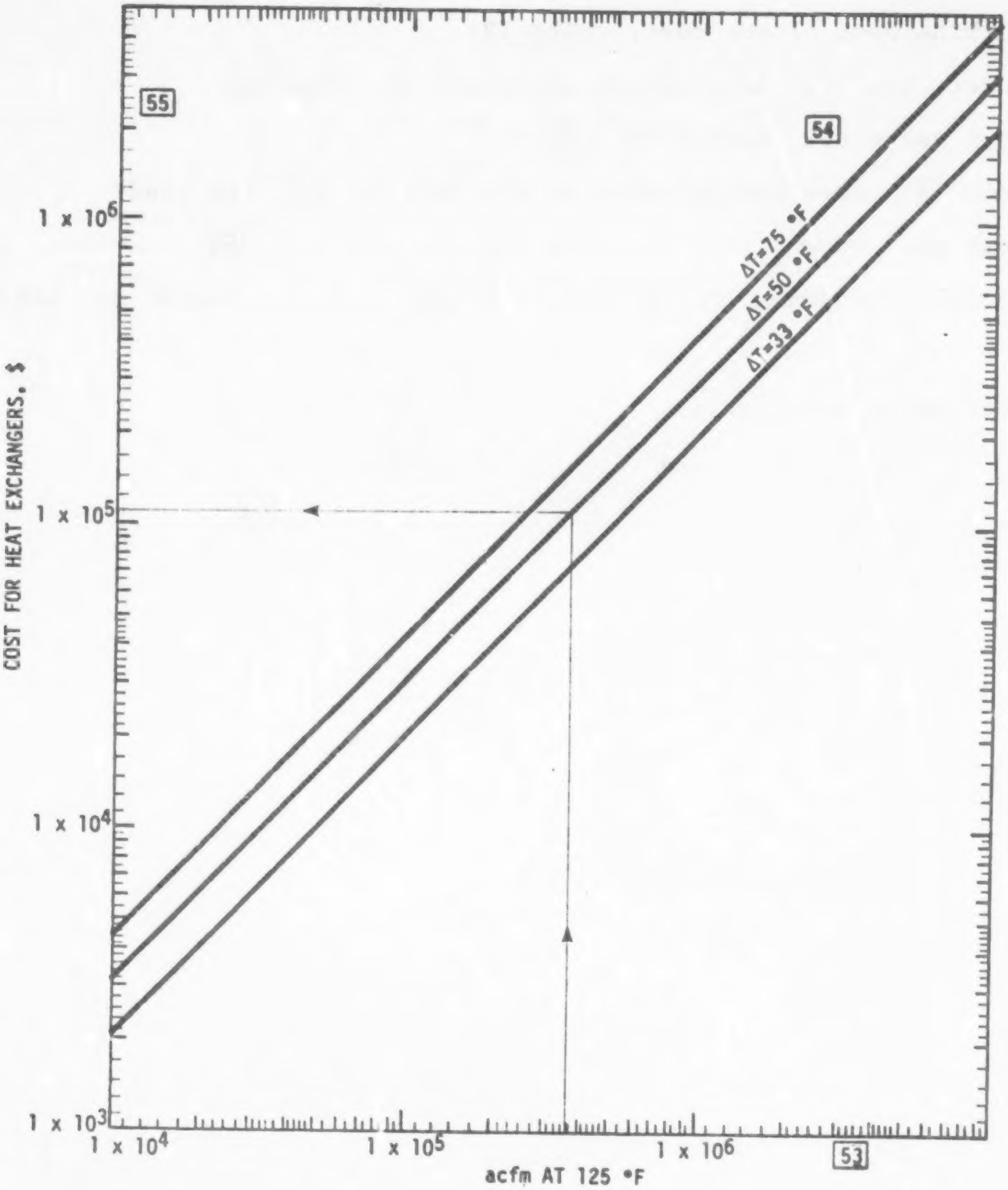


Chart 11. HEAT EXCHANGER COSTS

SOOT BLOWER COST

To determine soot blower cost, Chart 12:

Enter item $\boxed{23}$ from page A-11, Chart 12, item $\boxed{56}$

Move vertically upward to $\boxed{57}$

From $\boxed{57}$ move horizontally to the left to $\boxed{58}$ and read:

Cost per train . $______________ $\boxed{58}$

Record from page A-12, Chart 4, item $\boxed{24}$ __________, number of trains

Cost of soot blowers:

$\boxed{58} \times \boxed{24} = \boxed{59}$

$______________ x ______________ = $______________ $\boxed{59}$

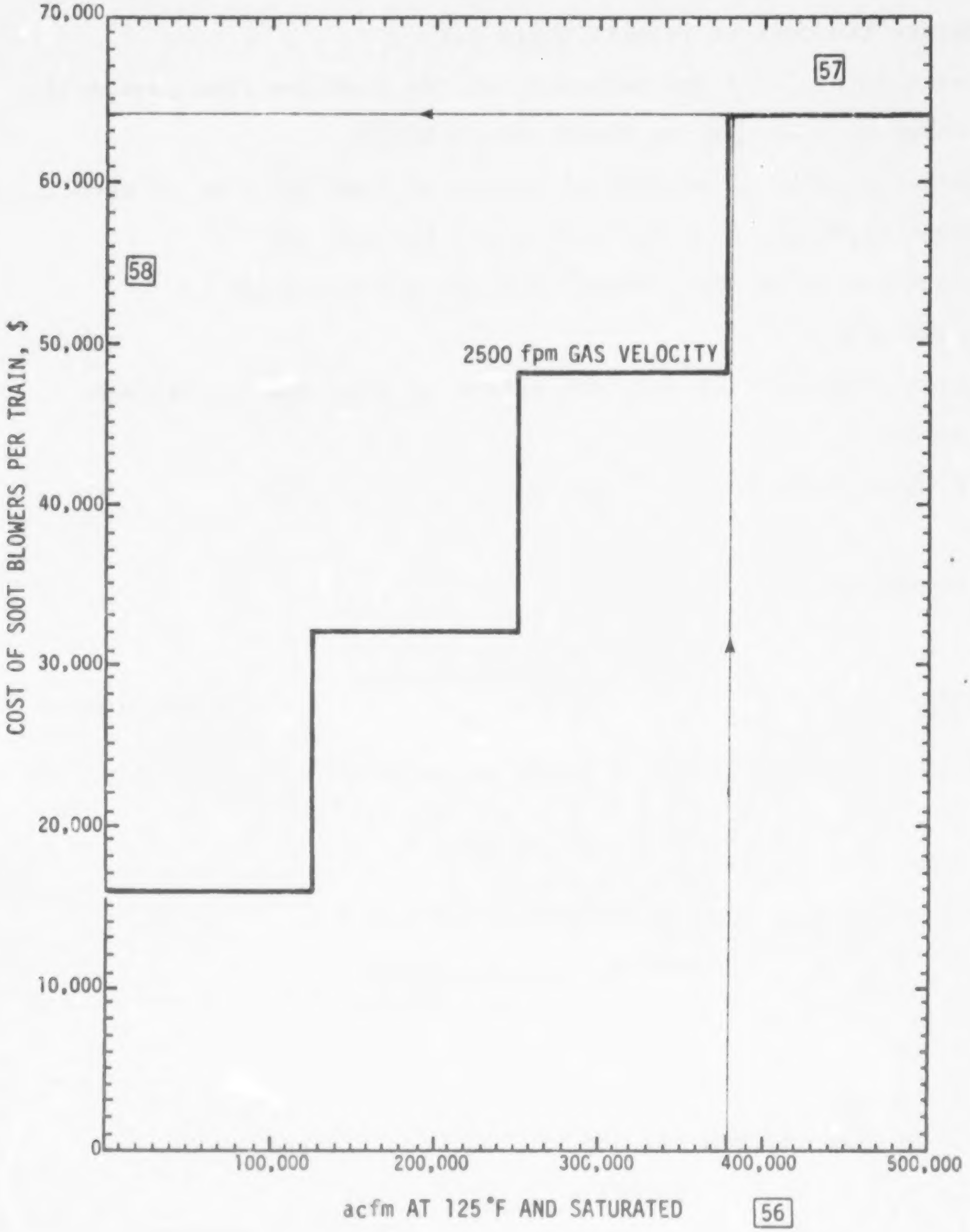


Chart 12. SOOT BLOWER COSTS

REHEAT COST

To calculate the cost of reheat, Chart 13:

Enter acfm at 125°F and saturated of the flue gas from page A-12 Chart 4, item $\boxed{22}$ on Chart 13, item $\boxed{60}$

Select and enter ΔT of 50°F of reheat on item $\boxed{61}$, or ΔT used_____°F

Connect items $\boxed{60}$ and $\boxed{61}$ and extend to item $\boxed{62}$

Enter costs ($/MM BTU) reheat* from calculation below on item $\boxed{63}$

Connect items $\boxed{62}$ and $\boxed{63}$ and extend to item $\boxed{64}$, read and record:

Cost ($/hr) reheat ____________________ $\boxed{64}$

Annual reheat cost:

$\boxed{64}$		Weighted capacity factor from data sheet,	= reheat cost/yr $\boxed{65}$
$_______________	x 8760 hr/yr	x 0.______________	= $_______________ $\boxed{65}$

*Reheat Cost -

Coal: To correct from 12,000 BTU/lb and $10/ton

$$=665 \times \frac{\_\_\_\_\_\_\_\_ (\$/\text{ton})}{\_\_\_\_\_\_\_\_ \text{ BTU/lb.}} = \$\_\_\_\_\_\_\_\_\_\_\_\_\_\_ /\text{MM BTU}$$

Oil: To correct from 149,000 BTU/gal. and $10/bbl

$$=31{,}707 \times \frac{\_\_\_\_\_\_\_\_ (\$/\text{bbl})}{\_\_\_\_\_\_\_\_ \text{ BTU/lb}} = \$\_\_\_\_\_\_\_\_\_\_\_\_\_\_ /\text{MM BTU}$$

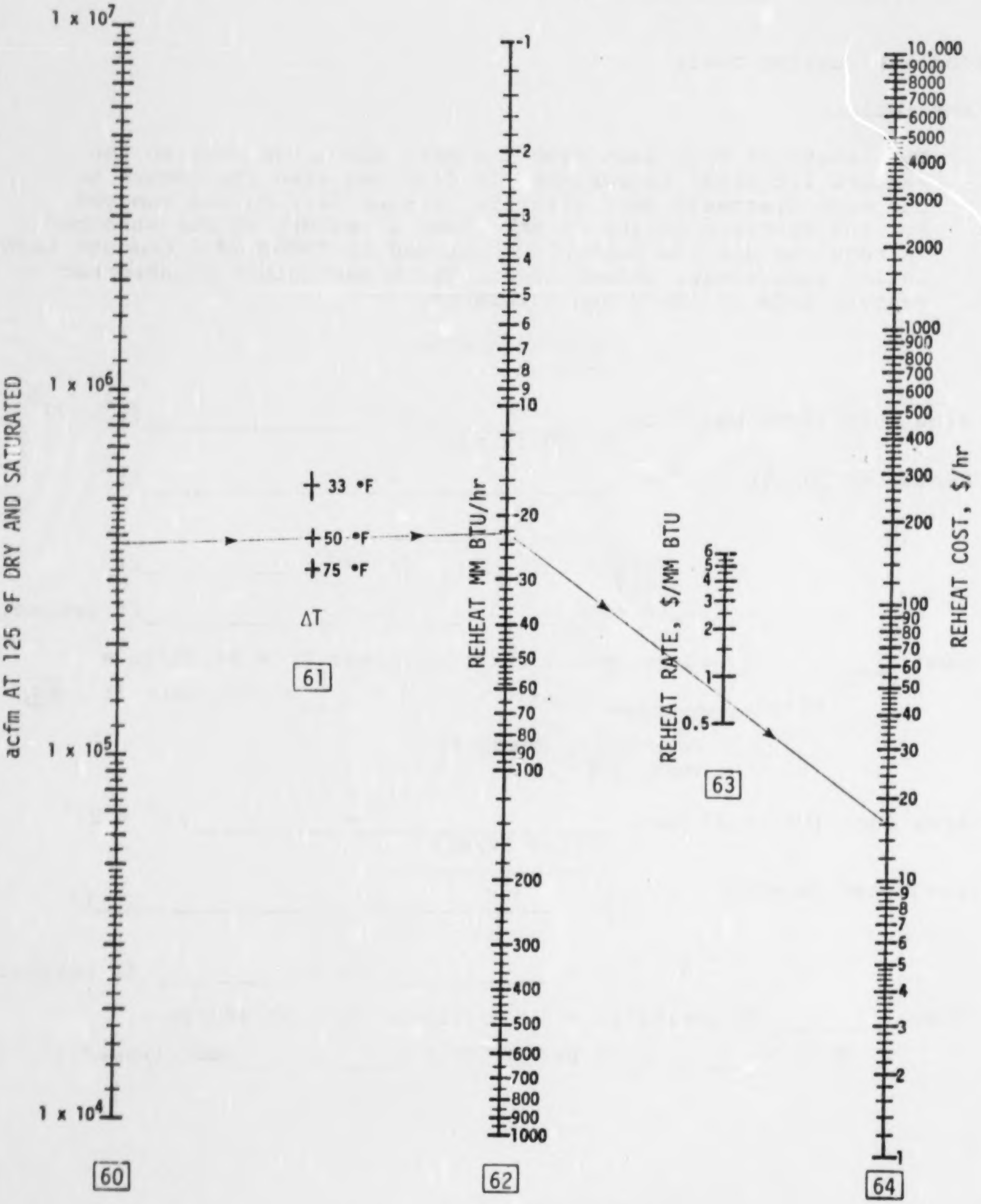


Chart 13. REHEAT COSTS

DUCT COSTS

To calculate ducting cost:

Assumption-

The length of flue duct from the main discharge duct to the venturi (if used) is variable in feet and also the return to the main discharge duct after SO_2 and/or particulate removal. For the specific boiler if more than 1 venturi and/or absorber is required use the multipliers listed in **Table 14.** Compute each boiler separately, unless identical to each other in absorber or venturi acfm at 125°F and saturated.

From data sheet,
acfm at °F

Area duct (from main) in: $\dfrac{\underline{\qquad\qquad}}{3{,}500\text{ ft/min}} = \underline{\qquad\qquad}\text{ ft}^2 = 2\lambda^2$

Perimeter length: $\lambda^2 = \dfrac{\underline{\qquad\qquad}}{2} = \underline{\qquad\qquad}\text{ ft}^2$

$\lambda = \sqrt{\dfrac{\underline{\qquad\qquad}}{2}\text{ft}^2} = \underline{\qquad\qquad}\text{ ft}$

$6\lambda = 6\text{x } \underline{\qquad\qquad}\text{ ft} = \underline{\qquad\qquad}\text{ ft perimeter}$

Cost: $\underline{\qquad\qquad}$ ft perimeter x 18 lb/linear ft x \$0.39/lb =
7.02 x $\underline{\qquad\qquad}$ ft perimeter = \$$\underline{\qquad}$ cost/linear ft $\boxed{66}$

Page A-11, Chart 4,
item $\boxed{22}$

Area duct (to main) out: $\dfrac{\underline{\qquad\qquad}}{2{,}500\text{ ft/min}} = \underline{\qquad\qquad}\text{ ft}^2 = 2\lambda^2$

Perimeter length: $\lambda = \sqrt{\dfrac{\text{ft}^2}{2}} = \underline{\qquad\qquad}\text{ ft}$

$6\lambda = 6\text{ x } \underline{\qquad\qquad}\text{ ft} = \underline{\qquad\qquad}\text{ ft perimeter}$

Cost: $\underline{\qquad\qquad}$ ft perimeter x 18 lb/linear ft x \$0.445/lb =
8.01 x $\underline{\qquad\qquad}$ ft perimeter = \$$\underline{\quad.\quad}$ cost/linear ft $\boxed{67}$

DUCT COST

Table 14. MULTIPLIER FOR DUCT COST

No. of absorbers and/or venturis per boiler	Venturi and absorber in	Venturi or absorber only in	Venturi plus absorber out	Venturi or absorber only out
1	110	70	70	50
2	190	114	113	93
3	250	180	143	123
4	305	225	175	155
5	356	266	205	183
6	410	310	235	208
7	453	346	262	242
8	490	378	288	268
9	535	415	315	295
10	579	452	343	324

Duct cost in -

(in) cost/linear ft x (Table 14 multiplier + Estimated ft to main duct*-30') = Duct cost (in) $\boxed{68}$

$\boxed{66}$ ____________ x (____________ + ____________ -30') = ____________ $\boxed{68}$

Duct cost out -

(out) cost/linear ft x (Table 14 multiplier + Estimated distance to main duct**-50') = Duct cost (out) $\boxed{69}$

$\boxed{67}$ ____________ x (____________ + ____________ -50') = ____________ $\boxed{69}$

Total duct cost -

$\boxed{68}$ duct cost (in) + $\boxed{69}$ duct cost (out) = $\boxed{70}$ total duct cost

$ ____________ + $ ____________ = $ ____________ $\boxed{70}$

---

* If congested area add 230 ft for estimated ft.

** If congested area add 200 ft for estimated ft.

LIME PREPARATION AREA COSTS

To calculate conveyor cost, Chart 15:

Step 1: Estimate distance (ft) from storage silo area to sites and record

________(ft) $\boxed{70}$ from storage silo area to silos (day bins)

Step 2: Record from page A-6, item $\boxed{10}$

____________lb/hr CaO

lb/hr CaO ÷ 2,000 = ____________ton/hr CaO $\boxed{71}$

Enter ton/hr Chart 15 at $\boxed{71}$ and move vertically upward

to $\boxed{72}$ then move horizontally to the left

to $\boxed{73}$ and record $______conveyor cost $\boxed{73}_C$

If $\boxed{70}$ is greater or less than 600 ft.

Enter ton/hr at $\boxed{71}$ and move vertically upward

to $\boxed{74}$ and then move horizontally to the left

to $\boxed{73}$ and record $______conveyor cost/100 ft $\boxed{73}_D$

Number of 100 ft lengths that $\boxed{70}$ is greater or less than

600 ft______$\boxed{75}_D$ **(estimated by the observer)**

$\pm (\boxed{73}_D \times \boxed{75}_D) =$ $ adjusted cost $\boxed{76}$

± (__________x_____________) = $ ±____________ $\boxed{76}$

Conveyor cost:

$\boxed{73}_C \pm \boxed{76} = \boxed{77}$

__________ ± ________________ = $ _________conveyor cost $\boxed{77}$

Assumptions:

Cost of the conveyor system installed: 2-inground hoppers, 2-15° incl. conveyors

(conveyor at 50' elev., conveyor covered , 2 trippers.)

Conveyor lengths: 2-300' inclined, 1-600' to silos, walkways.

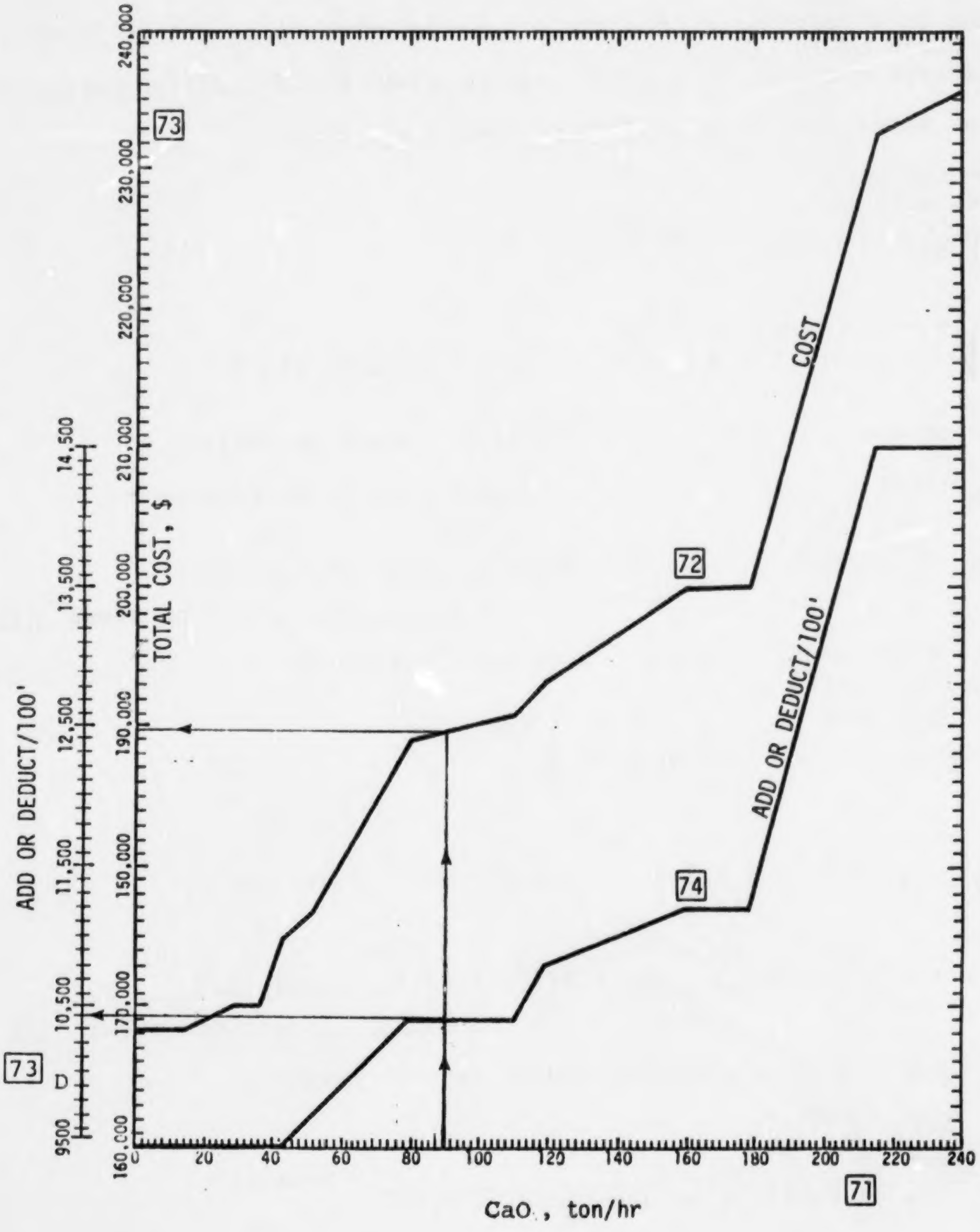


Chart 15. CONVEYOR COSTS

FLUE GAS SHUTOFF AND BYPASS VALVES

To calculate flue gas shutoff and bypass valve costs:

Assumption-

Based on 4 vanes/axis in short dimension based on height of 20 ft and width of 10 ft, Stainless steel at $141.6/ft^2; carbon steel at $99.1/ft^2 ; fabricated

Flue gas valve (in) at main duct to create a bypass

$$\frac{\text{From the data sheet acfm at }\_\_\_\_{}^{\circ}\text{F}}{3{,}500}\Big/\text{Boiler} = \_\_\_\_\_\_\_\_\ \text{ft}^2$$

$$W = \sqrt{\frac{\_\_\_\_}{2}\ \text{ft}^2}\ ;\ W \times 2 = \_\_\_\_\_ \times 2 = \text{height, ft, H.}$$

$$\text{Valve cost A} = (1.5 \times H)\ \left[(99.1) \pm^{*} (3.1)\ (H-20)\ (0.5H-10)\right]$$

*H greater than 20 ft, sign is +, less than 20 ft sign is -

$$= (1.5 \times \overset{H}{\_\_\_\_})\ \left[(99.1) \pm (3.1)\ (\overset{H}{\_\_\_}-20)\ (0.5\overset{H}{\_\_\_}-10)\right]$$

$$= \$\_\_\_\_\_\_\_\_\_\_\ \text{carbon steel} \quad \boxed{78}$$

Flue gas valve (out) at main duct to create a bypass

$$\frac{\text{Page A-12, chart 4, item } \boxed{22} \text{ acfm at }\_\_\_\_{}^{\circ}\text{F}}{2{,}500}\Big/\text{Boiler} = \frac{\boxed{22}}{2{,}500} = \_\_\_\_\_\_\_\_\ \text{ft}^2$$

$$W = \sqrt{\frac{\_\_\_\_}{2}\ \text{ft}^2}\ ;\ W \times 2 = \_\_\_\_\_ \times 2 = \_\_\_\_\_\ \text{ft(height H)}$$

$$\text{Valve cost B} = (1.5 \times \overset{(H)}{\_\_\_\_})\ \left[(141.6) \pm^{*} (4.5)\ (\overset{(H)}{\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_}-10)\right]$$

$$= \_\_\_\_\_\_\_\_\_\_\ \text{stainless steel} \quad \boxed{79}$$

Flue gas valve (in) to absorber and/or venturi train

$$\frac{\text{Page A-12, chart 4, item } \boxed{22} \text{ acfm at }\_\_\_\_{}^{\circ}\text{F}\ /\text{Boiler}}{(\boxed{24}\ \text{No. of venturis or absorbers}) \times 3{,}500} = \text{Area, ft}^2$$

FLUE GAS SHUTOFF AND BYPASS VALVES (continued)

$$\frac{\boxed{22}}{\boxed{24}\,\_\_\_\_\_\_ \times 3{,}500} = \_\_\_\_\_\_\_\_\_\_ = \text{Area, ft}^2 = 2W^2$$

$$W = \sqrt{\frac{\_\_\_\_\_\_}{2}}\ \text{ft}^2;\ W \times 2 = \_\_\_\_\_\_\_\_ \times 2 = \_\_\_\_\_\_\_\_ \text{ft, height (H)}$$

Valve cost C

$$= (\text{Height (H)} + 0.5\ \text{Height (H)}\ \left[(99.1)-(3.1)(H-20)\ (0.5H-10)\right]$$

$$= (1.5 \times \overset{(H)}{\_\_\_\_})\ \left[(99.1)-(3.1)\ (\overset{(H)}{\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_}-10)\right]$$

$$= \_\_\_\_\_\_\_\_\_\_ \text{carbon steel} \qquad \boxed{80}$$

Valve cost D =

$$\left(\frac{\text{Page A-11, item 24}}{\text{No. of venturis and/or absorbers}}\right) \times (\text{valve cost}_C\ \boxed{80}) = \qquad \boxed{81}$$

$$= (\_\_\_\_\_\_\_\_) \times (\_\_\_\_\_\_\_\_) = \$\_\_\_\_\_\_\_\_\_\_ \boxed{81}$$

Flue gas valve (out) from absorber and/or venturi

$$\frac{\text{Page A-12, Chart 4, item 22}}{\frac{1.08\ \text{acfm at } 175°F}{2{,}500}} \Big/ \text{Venturi and/or absorber} = \text{ft}^2$$

$$0.000432 \times \overset{\boxed{22}}{\_\_\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_ \text{ft}^2 = 2W^2$$

$$W = \sqrt{\frac{\_\_\_\_\_\_}{2}}\ \text{ft}^2;\ W \times 2\ \_\_\_\_\_\_\_\_ \times 2 = \_\_\_\_\_\_\_\_ \text{ft, (H)}$$

Valve cost$_E$ =

$$= (1.5\overset{(H)}{\_\_\_\_\_\_})\ \left[(141.6)-(4.5)\ (\overset{(H)}{\_\_\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_\_\_}-10)\right]$$

$$= \$\_\_\_\_\_\_\_\_\_\_ \text{stainless steel}\ \boxed{82}$$

Valve cost$_F$ =

$$\left(\frac{\text{Page A-11, item 24}}{\text{No. of venturis and/or absorbers}}\right) \times (\text{valve cost}_E\ \boxed{82}) = \qquad \boxed{83}$$

$$= (\_\_\_\_\_\_\_\_) \times (\_\_\_\_\_\_\_\_) = \$\_\_\_\_\_\_\_\_\_\_ \boxed{83}$$

Valving cost per boiler

$$\text{Valve cost}_G = \boxed{78} + \boxed{79} + \boxed{81} + \boxed{83} = \boxed{84}$$

$$= \quad V_A \quad V_B \quad V_D \quad V_F$$

$$= \_\_\_\_\_\_ + \_\_\_\_\_\_ + \_\_\_\_\_\_ + \_\_\_\_\_\_$$

$$= \$\_\_\_\_\_\_\_\_\_\_ \text{total valve cost} \qquad \boxed{84}$$

LIME OPERATING AND STORAGE SILO COSTS

To calculate costs of silos for operating 3 day and 12 day storage of lime, Chart 16:

Enter item $\boxed{71}$ * from page A-35, Chart 15 on Chart 16, item $\boxed{85}$

then move vertically upward to item $\boxed{86}$

then move horizontally left to item $\boxed{87}$ and read:

Cost for silos for operating 3 days $____________ $\boxed{87}^{*}_{A}$

Storage silo cost is based on storage capacities indicated:

Enter item $\boxed{71}$ from page A-35, Chart 15 on Chart 16, item $\boxed{85}$

then move vertically upward to item $\boxed{88}$

then move horizontally left to item $\boxed{87}$ and read:

Cost of 12 days storage silo $____________ $\boxed{87}^{*}_{B}$

. .

Fixation silo cost -

1/3 x item $\boxed{87}_{A}$ = $ cost $\boxed{89}$

.33 x____________ = $______________ $\boxed{89}$

______________ . ______________ . ______________

Lime cost for start-up, 12 day storage plus 3 days operating -

$\left(\begin{array}{l}\text{Item } \boxed{71} \\ \text{from} \\ \text{Chart 15}\end{array}\right)$ x $25./ton x 24 hours/day x 15 days = $ costs $\boxed{90}$

(____________)x 9000 = $________________ Lime costs $\boxed{90}$

to correct $\boxed{90}$ for current costs:

$$\boxed{90} \times \frac{\text{\$/ton current cost CaO}}{25} = \text{\$ corrected costs } \boxed{90}_{C}$$

$$\_\_\_\_\_\_ \times \frac{\_\_\_\_\_\_\_\_\_\_\_\_\_\_}{25} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_ \boxed{90}_{C}$$

LIME OPERATING AND STORAGE SILO COSTS (Continued)

* If tonnage usage is under 4.7 tons/hour of CaO use the table below for storage silo costs -

lb/hr	No. of silos	cost/ ancilliary equipment $\boxed{87}$ *A + B
0 - 500	1	9,000
501 - 2,000	1	15,000
2001 - 5,000	2	36,000
5001 - 9,400	3	65,000

_____ tons /hr $\boxed{71}$ = $________________ $\boxed{87}$ A + B

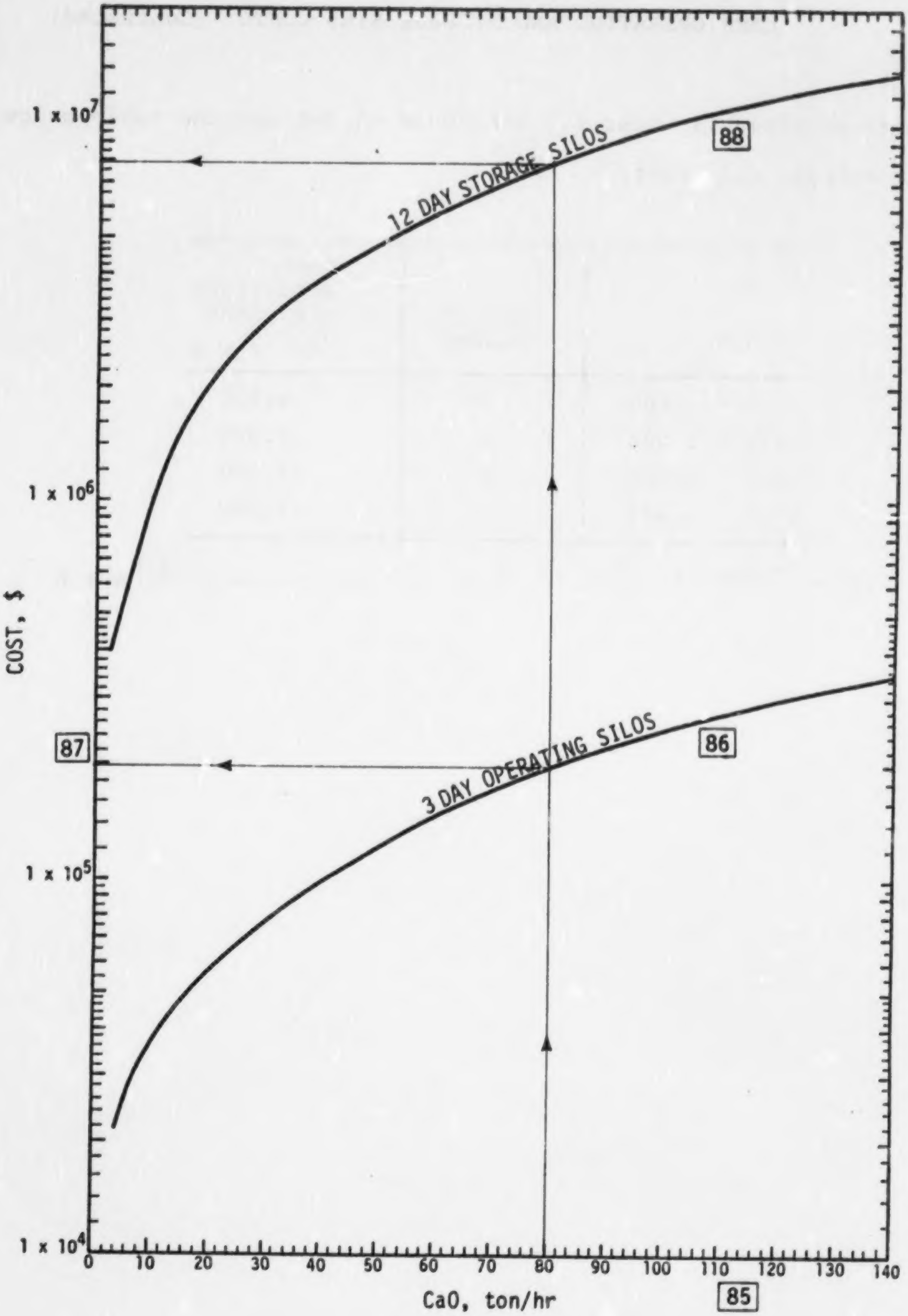


Chart 16. LIME OPERATING AND STORAGE SILO COSTS

SLURRY TANKS, MIXERS AND PUMPS COST

To calculate slurry tank costs, Charts 17, 18 and 19

Enter from page A-35, item $\boxed{71}$ Chart 15 on Chart 17 on item $\boxed{91}$, then connect item $\boxed{91}$ with 15%* on item $\boxed{92}$, extend to item $\boxed{93}$, read and record:

slurry storage gallons ______________ $\boxed{93}$

Select number of tanks required:

Maximum storage capacity per tank 600,000 gallons if $\boxed{93}$ is greater than 600,000 gallons, divide $\boxed{93}$ by a number up to 600,000 to get an even number of tanks ______ $\boxed{94}$

If storage capacity is less than 34,170 gal.:

Enter item $\boxed{93}$ on Chart 18, item $\boxed{95}$, move vertically upward to item $\boxed{96}$, then move horizontally left to item $\boxed{97}$, read and record:

Total cost of slurry storage tank $ ______________ $\boxed{97}$

If storage capacity is between 34,170-600,000 gal.:

Enter item $\boxed{93}$ on Chart 19, item $\boxed{98}$, move vertically upward to item $\boxed{99}$, then move horizontally left to item $\boxed{100}$, read and record:

Total cost of slurry storage tank $ ______________ $\boxed{100}$

If storage capacity is over 600,000 gal.:

Divide $\boxed{93}$ by $\boxed{94}$, record gallons per tank $\boxed{101}$

__________ ÷ __________ = ______________ $\boxed{101}$

*If slurry percentage other than 15%, use available value.

SLURRY TANKS, MIXERS AND PUMPS COST (Continued)

Enter item $\boxed{101}$ on Chart 19, item $\boxed{98}$, move vertically upward to item $\boxed{99}$, then move horizontally to item $\boxed{100}$, read and record cost of each tank.

Cost of each slurry tank $______________ $\boxed{100}$

Total cost of slurry storage tanks

= cost/tank $\boxed{100}$ x No. of tanks $\boxed{94}$ = $\boxed{102}$

= ______________ x ______________

= $______________ $\boxed{102}$

Mixer cost

From Chart 17, item $\boxed{93}$ ** note the storage capacity required, then select proper range from Table 20, under tank capacity, gal. item $\boxed{103}$ (if $\boxed{93}$ is less than 600,000 gal.)

No. of mixers______________ $\boxed{104}$

Total mixer costs $______________ $\boxed{105}$

** if item $\boxed{93}$ is greater than 600,000 gallons then enter item $\boxed{101}$ on item $\boxed{103}$ to determine number of mixers required -

No. of mixers/tank__________ $\boxed{104}$

Mixer cost/tank__________ $\boxed{105}$

No. of tanks__________ $\boxed{94}$

Total mixer cost = $\boxed{105}$ x $\boxed{94}$ = $ $\boxed{106}$

______________ x ______ = __________ $\boxed{106}$

SLURRY TANKS, MIXERS AND PUMPS COST (Continued)

Pump cost

Enter from page A-35, item $\boxed{71}$ Chart 15 on Chart $\boxed{21}$ on item $\boxed{107}$, then connect item $\boxed{107}$ with slurry percentage on item $\boxed{108}$, extend to item $\boxed{109}$

Connect item $\boxed{109}$ with 200 ft head on item $\boxed{110}$, extend to item $\boxed{111}$, read and record:

Pump costs/tank $________ $\boxed{111}$

Total pump costs = $\boxed{111}$ x 94 = $ $\boxed{112}$

________ x ________ = $ ________ $\boxed{112}$

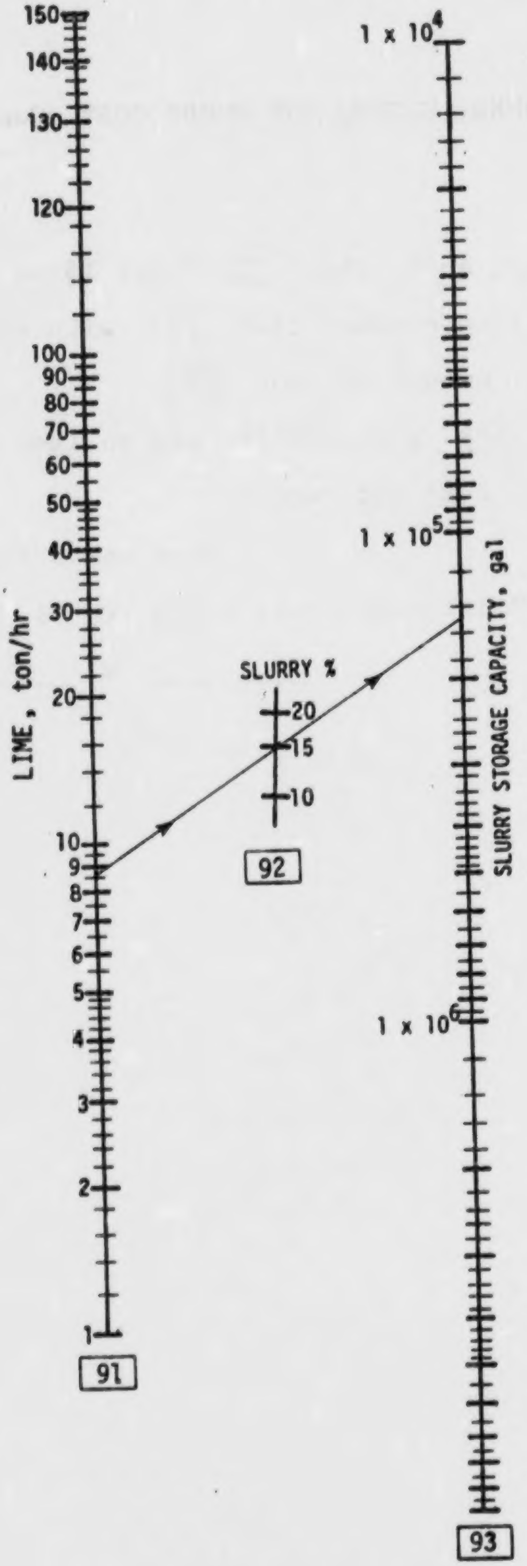
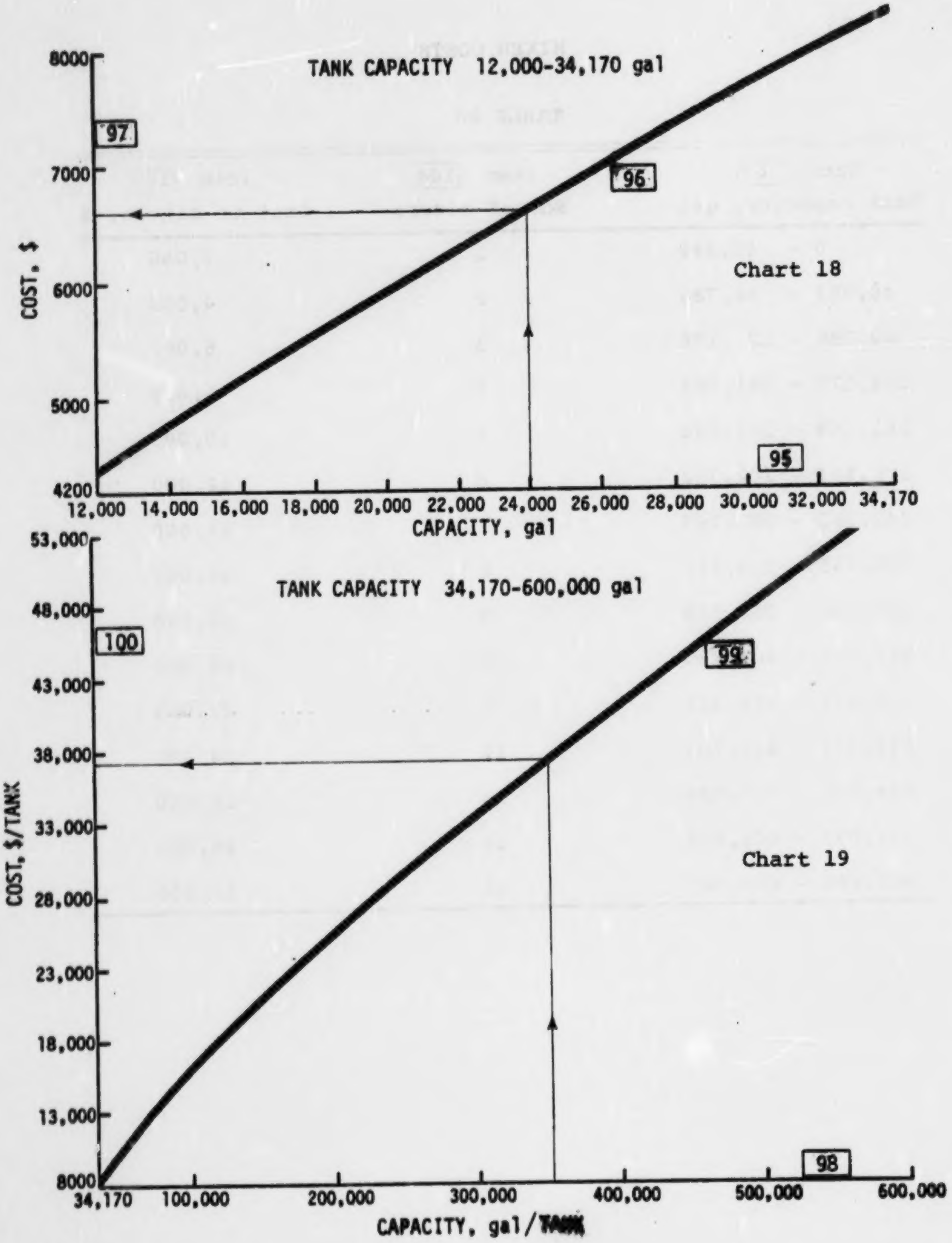


Chart 17. SLURRY TANKS, MIXERS AND PUMPS COST



Charts 18 and 19. SLURRY TANKS, MIXERS AND PUMPS COST

MIXER COSTS

TABLE 20

Item 103 Tank capacity, gal.	Item 104 No. of mixers	Item 105 Cost of mixers, $
0 - 40,392	1	2,000
40,393 - 80,784	2	4,000
80,785 - 121,176	3	6,000
121,177 - 161,568	4	8,000
161,569 - 201,960	5	10,000
201,961 - 242,352	6	12,000
242,353 - 282,744	7	14,000
282,745 - 323,136	8	16,000
323,137 - 363,528	9	18,000
363,529 - 403,920	10	20,000
403,921 - 444,312	11	22,000
444,313 - 484,704	12	24,000
484,705 - 525,096	13	26,000
525,097 - 565,488	14	28,000
565,489 - 600,000	15	30,000

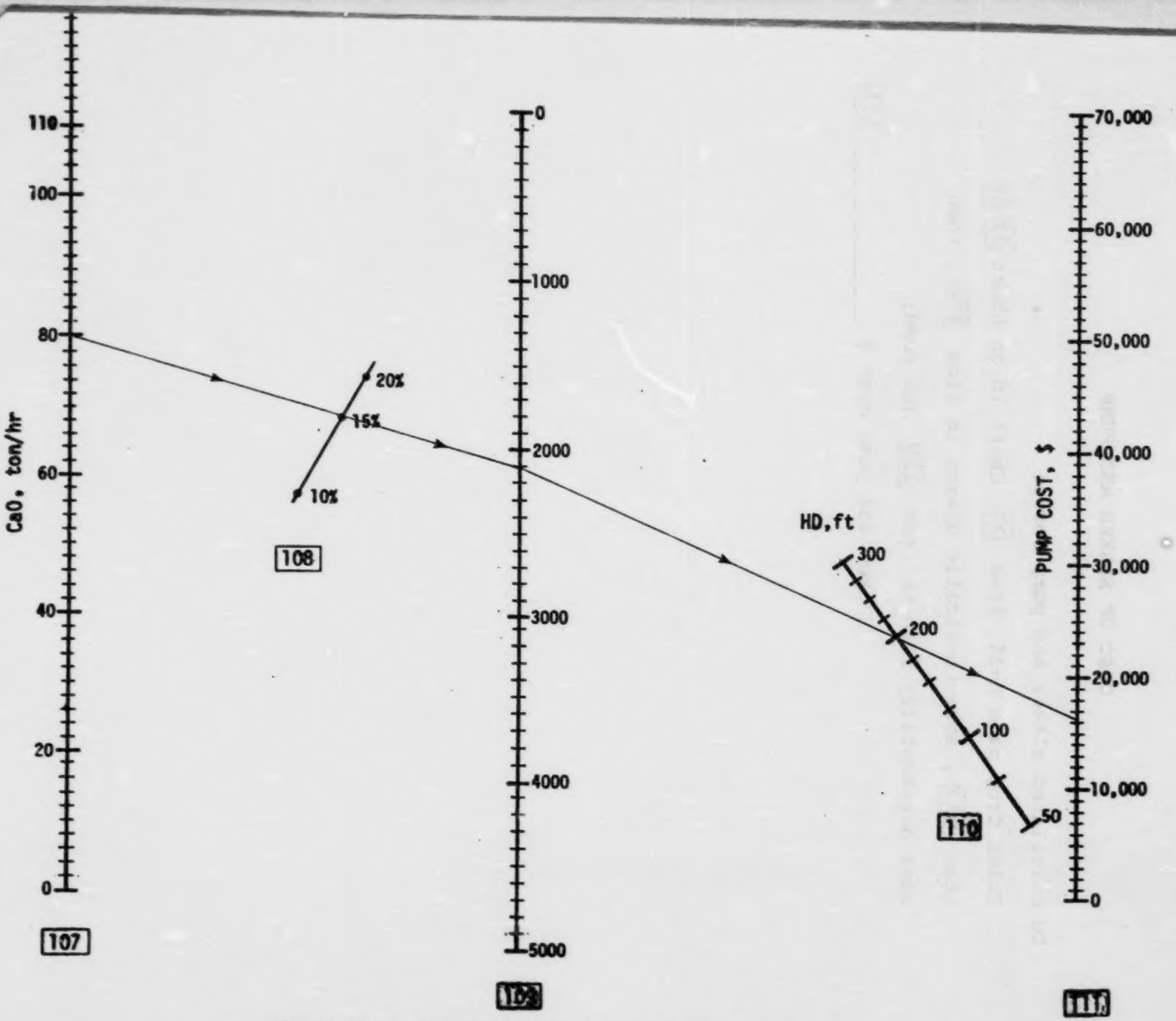


Chart 21. SLURRY TANKS, MIXERS AND PUMPS COST

COST OF SLAKER AND PUMP

To calculated slaker and pump costs:

Enter from page A-35, item $\boxed{71}$ Chart 15 on Chart $\boxed{22}$ on item $\boxed{113}$, move vertically upward to item $\boxed{114}$, then move horizontally left to item $\boxed{115}$ and read:

Slaker and pump cost $ ______________ $\boxed{115}$

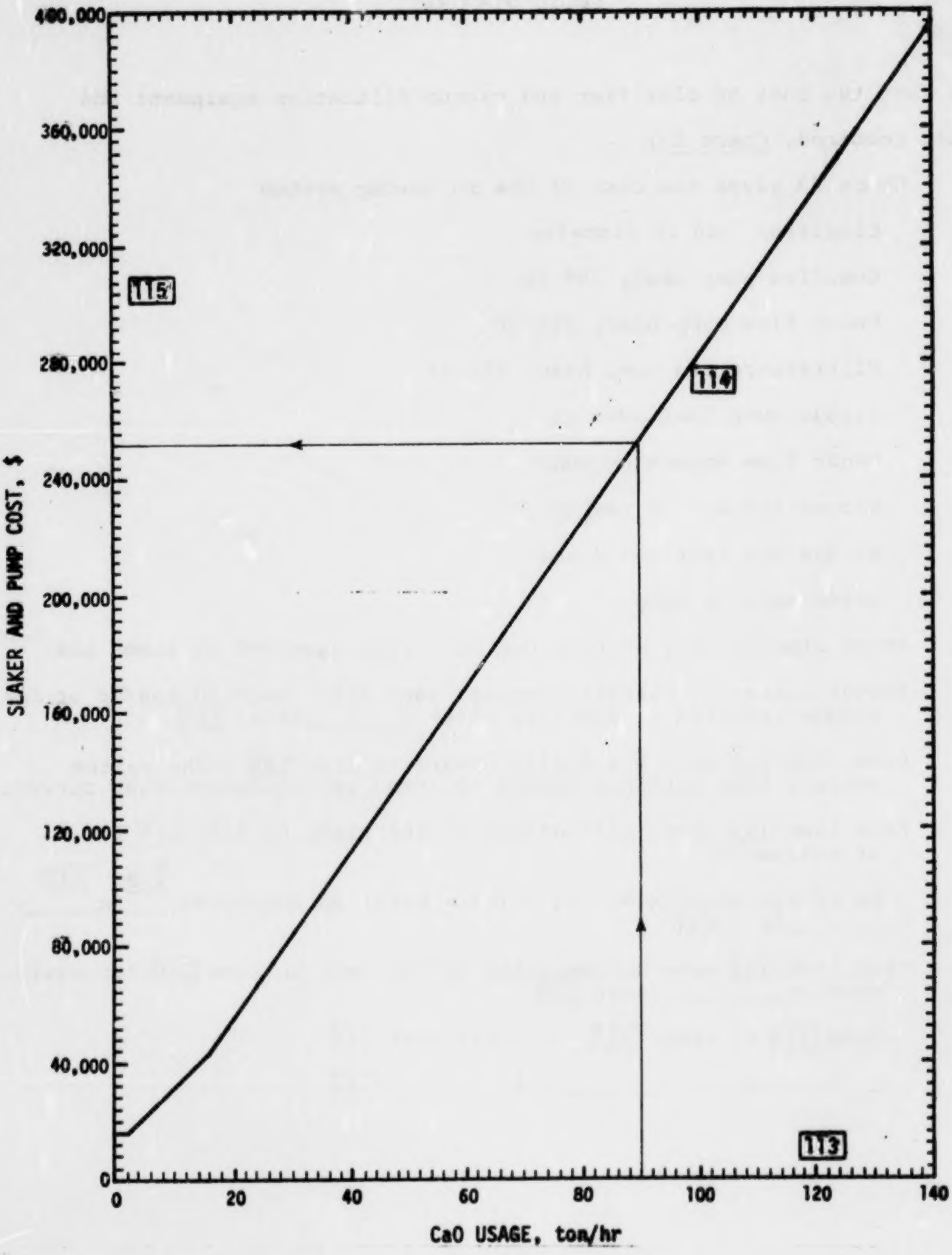


Chart 22. SLAKER AND PUMP

SOLID DISPOSAL

To find the cost of clarifier and vacuum filtration equipment and pump combined, Chart 23:

Chart 23 gives the cost of the following system

Clarifier 150 ft diameter

Overflow pump head, 250 ft

Under flow pump head, 250 ft

Filtrate-return pump head, 350 ft

Sludge pump head 1000 ft

Under flow emergency pump

Vacuum filter, 50 ton/hr

Sludge mix tank and mixer

Water make-up pump

Enter item 16 (dry sludge, ton/hr), from page A-9 on item 116

Select number of clarifier units, same size (each 50 ton/hr of dry sludge requires 1 clarifier unit) = ______ units 117

From item 116 move vertically upward to item 128 (Bhp system curve), then continue upward to item 118 (equipment cost curve).

From item 117 move horizontally to the right to item 119 for hp of equipment.

hp of equipment x No. of units = total hp required= ______ x ______ =
119 117
________ hp 121

From item 118 move horizontally to the left to item 120 for equipment, $__________/unit 120

Item 120 x item 117 = total cost 122

__________ x ________________ = $__________ 122

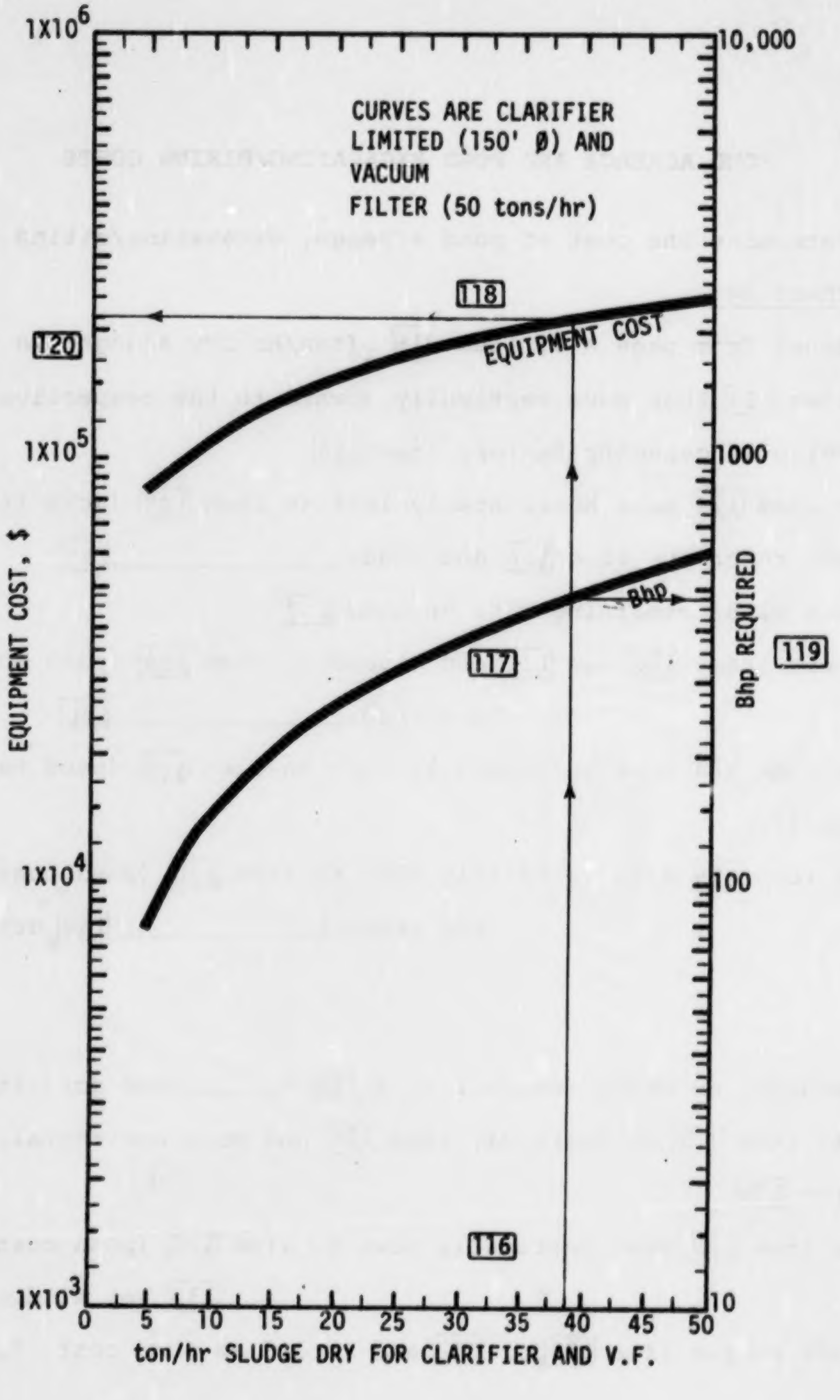


Chart 23. SOLID DISPOSAL

POND ACREAGE AND POND EXCAVATING/DIKING COSTS

To determine the cost of pond acreage, excavating/diking costs,

Chart 24:

Enter from page A-9, item $\boxed{16}_A$ (ton/hr dry sludge) on Chart 24, item $\boxed{123}$ then move vertically upward to the respective weighted capacity factor, item $\boxed{124}$

From item $\boxed{124}$ move horizontally left to item $\boxed{125}$ (acre ft/yr) and reference line $\boxed{126}$ and read: ________________ $\boxed{125}$

Select plant remaining life on item $\boxed{127}$

Connect items $\boxed{126}$ and $\boxed{127}$ and extend to item $\boxed{128}$ (pond acre ft)

and read: ________________ $\boxed{128}$

From item $\boxed{128}$ move horizontally left to item $\boxed{129}$ (pond reference scale)

From item $\boxed{129}$ move vertically down to item $\boxed{130}$ (pond cost)

and read: $ ________________ $\boxed{130}_p^{*}$ dry sludge

*If wet sludge, no waste return 1.67 x $\boxed{128}$ = ______ pond acre-ft wet sludge $\boxed{1}$

Enter item $\boxed{131}$ on Chart 24, item $\boxed{128}$ and move horizontally left to item $\boxed{129}$

From item $\boxed{129}$ move vertically down to item $\boxed{130}$ (pond cost) and read:

$ ______________________ $\boxed{132}$ wet sludge

Select proper item $\boxed{130}_p$ or $\boxed{132}$ and record as pond cost, $ __________ $\boxed{132}$

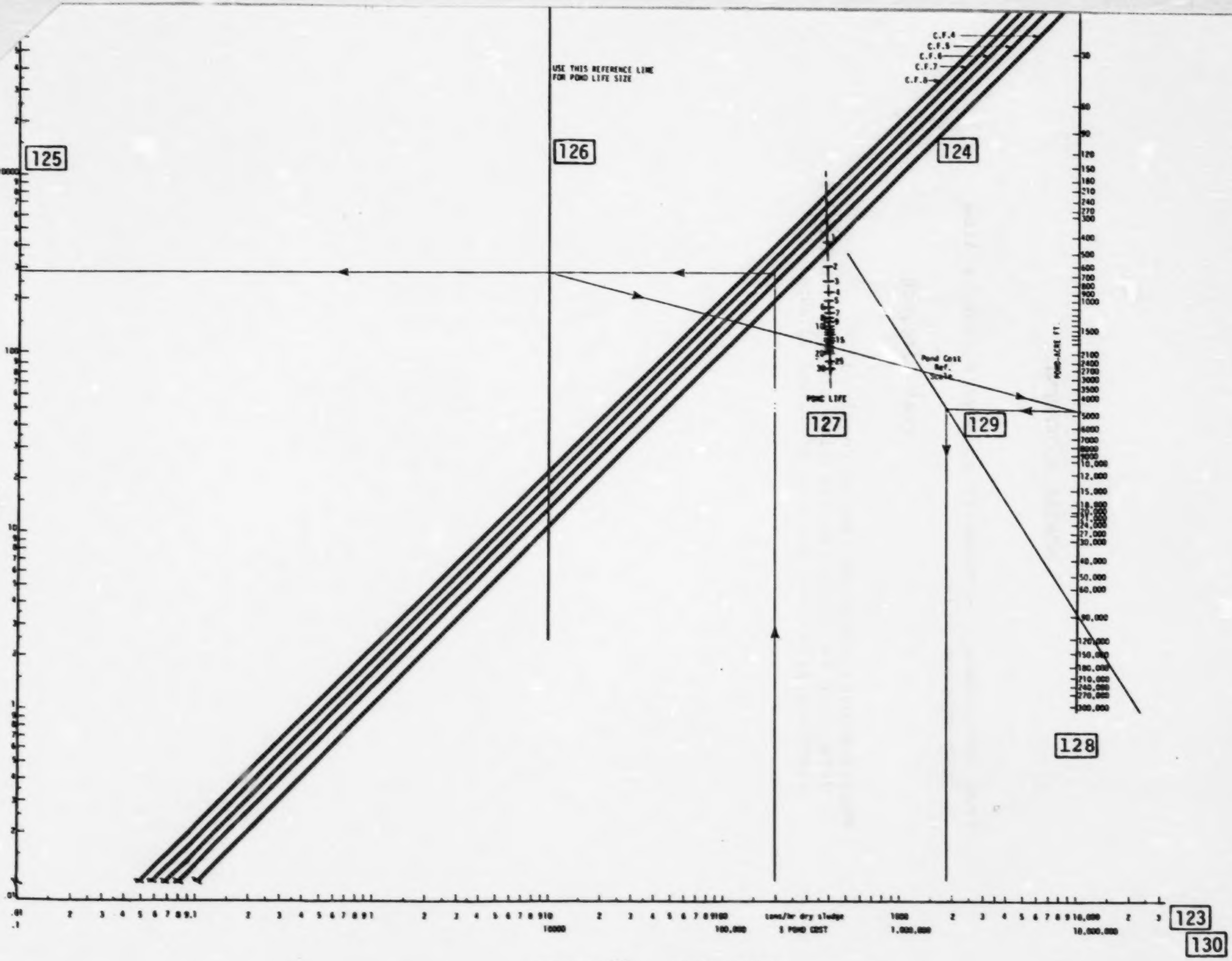


Chart 24. POND COST

MOBILE EQUIPMENT

From Richardson's - capacity to move 60 ton/hr lime from storage pile

Cost $44,000

Requirements: based on ton/hr required

- Same unit as above for fixation process capable of handling 1,300,000 gal./wk of fixed sludge

EQUIPMENT COST - LIME

Equipment	Item	Cost $
1. Absorber	$\boxed{27}$ A	
2. Venturi and Absorber	$\boxed{27}$ V+A	
3. Venturi	$\boxed{27}$ V	
4. Absorber and/or Venturi holding tanks agitators	$\boxed{35}$	
5. Absorber and/or Venturi holding tanks	$\boxed{39}$	
6. Circulation holding tank pumps	$\boxed{49}$	
7. I.D. Fans	$\boxed{52}$	
8. Heat Exchangers	$\boxed{55}$	
9. Soot Blowers	$\boxed{59}$	
10. Ducting	$\boxed{70}$	
11. Conveyors	$\boxed{77}$	
12. By-Pass Valving	$\Sigma\ \boxed{84}$	
13. 3 Day Storage Silos	$\boxed{87}$ A or $\boxed{87}$ A+B	
14. 12 Day Storage Silos	$\boxed{87}$ B	
15. Fixation Silo	$\boxed{89}$	
16. Lime slurry hold tanks	$\boxed{97}$ or $\boxed{100}$	
17. Lime Mixers (hold tank)	$\boxed{105}$ or $\boxed{106}$	
18. Lime Pumps (holding tank)	$\boxed{112}$	
19. Slaker, etc.	$\boxed{115}$	
20. Solids disposal-clarifier, vacuum filtration, pumps	$\boxed{122}$	
21. Mobile Equipment		
22. New roadways or RR siding at $50/ft., estimated length		
	Total Equipment Cost	

EQUIPMENT COST

Total costs:

Year of FGD system operation

Select from cost factor index multiplier from chart 25 for the year above

Predicted costs of equipment

(total costs) x (cost factor index multiplier)

(__________) x (______________) = $______________

Predicted pond cost

= (Pond cost from $\boxed{130}_p$ or $\boxed{132}$)x(cost factor index multiplie

= ____________________ x ______________________

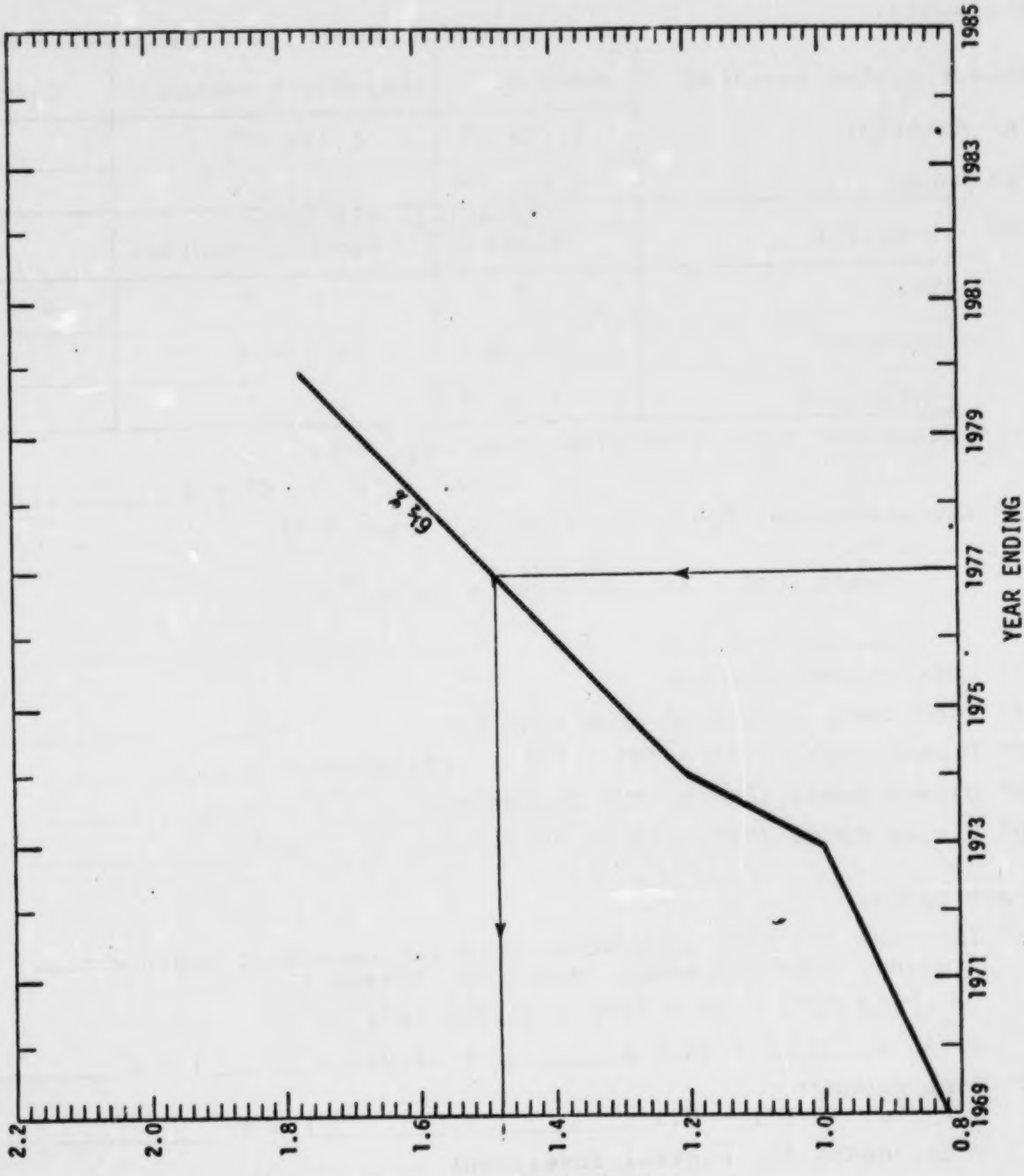

C.E., EQUIPMENT COST INDEX FACTOR
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
YEAR ENDING
1969
1971
1973
1975
1977
1979
1981
1983
1985
6¼ %

Chart 25

CAPITAL INVESTMENT COSTS--LIME

Direct costs:

Select system required	Absorber	Absorber & venturi	Cost,$
"A" Material	$1.646\ \lambda^a$	$1.639\ \lambda^a$	
"B" Labor	$0.814\ \lambda^a$	$0.822\ \lambda^a$	
	Materials and labor		
"C" Retrofit	Absorber	Absorber-venturi	—
Easy	0	0	______
Moderate	$0.047\lambda^a$	0.039λ a	
Difficult	$0.093\lambda^a$	$0.077\lambda^a$	

$^a\lambda$ = Equipment cost, predicted from page A-56

"A" + "B" + "C" = $______________

"D" Raw materials: Chart 15, item $\boxed{71}$ page A-34

ton/hr CaO x 15 day storage x $/ton^b =

______________ x 360 x __________ = $______________

^{b}If unknown use $25/ton

"E" Pond cost, predicted from page A-56 = $____________

"F" Direct costs ("A" + "B" + "C" + "E") above = $____________

"G" Direct costs ("A" to "E" inclusive) = $____________

"H" Direct costs ("A" + "B" + "C") above = $____________

Indirect costs:

"J" Interest (at 8%), contractor fees and expenses, engineering, freight, off-site, taxes, start-up, spares -

(0.33 "G") + (0.1 "H") + (0.065 "F") =

(0.33 x______) + (0.1 x _______) + (0.065 x _______) = $____________

"K" Contingency:
0.2 ("J" + "F") = 0.2 (_________+_________) = $____________

"L" Total costs for capital investment

"G" + "J" + "K" = _________+_________+_________

= $____________

Cost/Kilowatt:

$$\frac{L}{MW's \times 1,000} = \frac{\_\_\_\_\_\_\_\_}{\_\_\_\_ \times 1,000} =$$

$____________/Y

LIME SCRUBBING

TOTAL ANNUAL OPERATING COSTS--LIME

Utilities -

Water: Lime scrubbing

64 gal./MW for 3.0% S coal $\boxed{133}$

$\pm\Delta$ 5.5 gal./MW for each ± 1.0% S in coal $\boxed{134}$

52 gal./MW for 3.0% S oil $\boxed{135}$

$\pm\Delta$ 4 gal./MW for each ± 1.0% S in oil $\boxed{136}$

Lime

(gal./MW ± gal./MW corr. for % S) x hr/yr x weighted capacity fact. x water costs/1000 gal.) = yearly cost water/MW $\boxed{137}$

$\boxed{133}$ or $\boxed{135}$ ± $\boxed{134}$ or $\boxed{136}$

$\left(\_\_\_\_\_\_\_\_ \pm \_\_\_\_\_\_\_\_\right) \times \frac{\$0.02}{1000} \times 8760 \times$ cap. factor ______. = $/MW

$ ______ $\boxed{137}_A$

$\begin{pmatrix}\text{Coal or}\\ \text{Oil}\end{pmatrix}$; $\begin{pmatrix}\text{Base}, \% \text{ S}\\ \% \text{ S}, \text{corr.}\end{pmatrix}$ $\boxed{137}_A$ x MW = $\boxed{137}$

(______) ; (___ , ___) ; ______ x ______ = $ ______ /yr

Reheat:

From page A-31, Chart 13, item $\boxed{65}$ determine $/reheat

(see calculation sheet)

$ ________ /yr $\boxed{65}$

For ΔT ______ °F

TOTAL ANNUAL OPERATING COSTS--LIME

Operating labor cost:

MW's	Men/Shift
100- 699	3.16
700-1200	3.33
1201-2500	4.50
2501-	5.33

Men/shift x hr/yr x $/hr =

__________ x 8760 x 6.50 =

__________ x 56,940 = $ ______________ /yr $\boxed{138}$

Corrected cost: $\boxed{138} \times \left(\frac{\$/\text{hr (manpower)}}{6.50}\right) = \$$ ________ /yr $\boxed{138}$ C

Supervision:

0.15 x 56,940 x men/shift = $\boxed{139}$

8541 x ____________ = $ ____________ /yr $\boxed{139}$

Corrected cost: $\boxed{138}_{C} \times .15 = \$$ ______________ /yr $\boxed{139}$ C

Maintenance:

Capital costs, total

0.046 x ______________________ = $ ___________ /yr $\boxed{140}$

Overhead:

Capital cost, total + Men/shift

(0.023 x ___________) + (13,100 x ______) =

(______________________)+(____________________)=

= $ ________________ /yr $\boxed{141}$

TOTAL ANNUAL OPERATING COSTS--LIME

Fixed costs -

A. $\frac{100}{\text{Plant life, yrs*}}$ = ____________ %/yr depreciation, straight-line

B Capital = %/yr ________ %

C. Taxes, insurance, interim replacement - 4.65%

Total fixed costs = $\frac{A + B + C}{100}$ = ______ %/yr fixed costs

(fixed costs,%/yr) x(total capital cost) =

(____________ %/yr) x(________________)= $ ____________ /yr $\boxed{142}$

Sludge disposal:

Pumping to another site, off-plant

MW KW/MW $/KWH**or*** hr/yr x weighed CF

0.0011 x ________ x 1000 x ___________ x 8760 x ________ =

MW $/KWH** or *** weighed CF

9.64 x ________ x ________________ x ____________ = $ ______________ /yr $\boxed{143}$

Truck disposal costs/14 miles:

$\frac{\text{ton dry sludge/hr}}{\text{8.47 tons dry sludge/truck hr}}$ x $17.20 x 1.1 x 8760 x CF =

(57.25 min/trip) ($17.20/truck hr/driver)

From Chart 3, item $\boxed{16}$, tons dry sludge/hr ____________________ $\boxed{16}$

$\boxed{16}$ weighed CF

____________ x 19,570 x ______________ = $ ____________ /yr $\boxed{144}$

* Plant life, years: either remaining boiler life in years from start of FGD system or 15 year life for FGD system, use lowest number of years for life.

** or *** see page A-63

TOTAL ANNUAL OPERATING COST--LIME

Raw materials -

Lime:

Page A-35 Chart 15, item 71 ____ ton/hr CaO x hr/yr x weighed CF x $/ton[a] = cost/yr. $\boxed{145}$

= 8760 x CF x $/ton[a] x Chart 15, item $\boxed{71}$ =

= 8760 x__________x____________x_____________________ = $________ $\boxed{1}$

Fixation

Chart 3, item $\boxed{16}$ page A-10 lb/hr dry sludge x hr/yr x weighed CF x $/ton[b] x 1/2000 lb ton =

= 4.38 x CF x Chart 3, item $\boxed{16}$ = cost per year $\boxed{146}$

_______x_______x______________________ = $______________ $\boxed{146}$

Utilities:

Electrical, use appropriate

Lime--burning coal =

MW x x $/KWH** or *** x weighed CF x hr/yr = $ cost/yr

0.022 x________x 1000 x__________x__________x 8760 = $______ $\boxed{147}$

MW $/KWH** or *** CF

= 1.93 x 10^5 x______x______x________ = $____________/yr = $\boxed{147}$ A+V
(on coal/abs. + vent.)

MW $/KWH** or *** CF

= 1.84 x 10^5 x______x______x________ = $____________/yr = $\boxed{147}$A
(on coal/abs.)

Lime--burning fuel oil =

MW $/KWH** or *** CF

1.314 x 10^5 x______x______x________ = $____________/yr = $\boxed{147}$O
(on oil/abs.)

[a] or [b] or ** or *** see next page

LIME SCRUBBING

a If unknown use $25/ton.

b If unknown use $4/ton

** If unknown use 0.00675/KWH based on coal at $10/ton and 12,000 BTU/lb.

*** If unknown use 0.0185/KWH based on oil at $8.40/bbl and 149,000 BTU/gal.

TOTAL ANNUAL OPERATING COSTS - LIME

Summary sheet

	Item	Cost, $
1. Water	137	
2. Reheat	65	
3. Operating labor	138 c	
4. Supervision	139 c	
5. Maintenance	140	
6. Overhead	141	
7. Fixed costs	142	
8. Sludge disposal, pumping	143	
9. Sludge disposal, trucking	144	
10. Lime	145	
11. Fixation	146	
12. Electrical	147 A+V	
	147 A	
	147 O	
	Total annual operating costs	

Cost per kilowatt-hour:

$$\frac{\text{(total annual operating cost)}}{\text{hr/yr} \times \text{(plant rating in MW's)} \times 1{,}000 \times \text{(weighed capacity factor)}} =$$

$$\frac{(\qquad\qquad)}{8760 \times (\qquad) \times 1{,}000 \times (\qquad)} = \$\_\_\_\_\_\_\_\_/\text{KWH}$$

APPENDIX B

LIMESTONE SCRUBBING

NOTE: For purposes of clarity and continuity, Tables and Charts have been numbered sequentially in this report with no differentiation between Tables and Charts.

INFORMATION REQUIRED

Boiler No.						
Type of furnace						
MW at maximum continuous						
Age of unit , years						
Life, years remaining						
Capacity factor, yr._____						
Maximum continuous fuel, ton/hr or gal./min						
Maximum continuous, MM BTU/hr						
acfm at___°F						
Fly ash/total ash, %						
Efficiency of existing particulate control,%						

Cost of electricity/KW (Plant) =$________ . Cost of water/M gal. (Plant) = $____________

Coal, cost/ton $__________

% sulfur by weight __________

% ash by weight __________

HHV, BTU/lb __________

Oil, cost/bbl $__________

% sulfur by weight __________

BTU/gal __________

Specific Gravity __________

SO_2 permissible __________ lb SO_2/MM BTU } State or

Fly ash permissible__________ lb fly ash/MM BTU } Federal regulations

INFORMATION REQUIRED (continued)

Estimated land cost per acre (current) $__________

Possible interference determining the location of flue gas desulferization (FGD) system:

Congestion between stack and plant ☐ Yes ☐ No

Congestion between stack and/or plant with property line, coal pile, etc. ☐ Yes ☐ No

Identify problem areas and location: ______________________________

Terrain ______________________________

Conduits ______________________________

Possible obstructions ______________________________

Source of $CaCO_3$ available ______________________________

and % purity __________

SO_2 EMISSION DETERMINATION

To determine the SO_2 emissions (lb/MM BTU) in the flue gas, Chart 1:

Enter % sulfur by weight of fuel (oil or coal) on $\boxed{1}$

Enter heating value of fuel (BTU/lb) on $\boxed{2}$

Connect $\boxed{1}$ and $\boxed{2}$ and extend to $\boxed{3}$ and record and read:

SO_2 emissions (lb/MM BTU) in flue gas __________ $\boxed{3}$

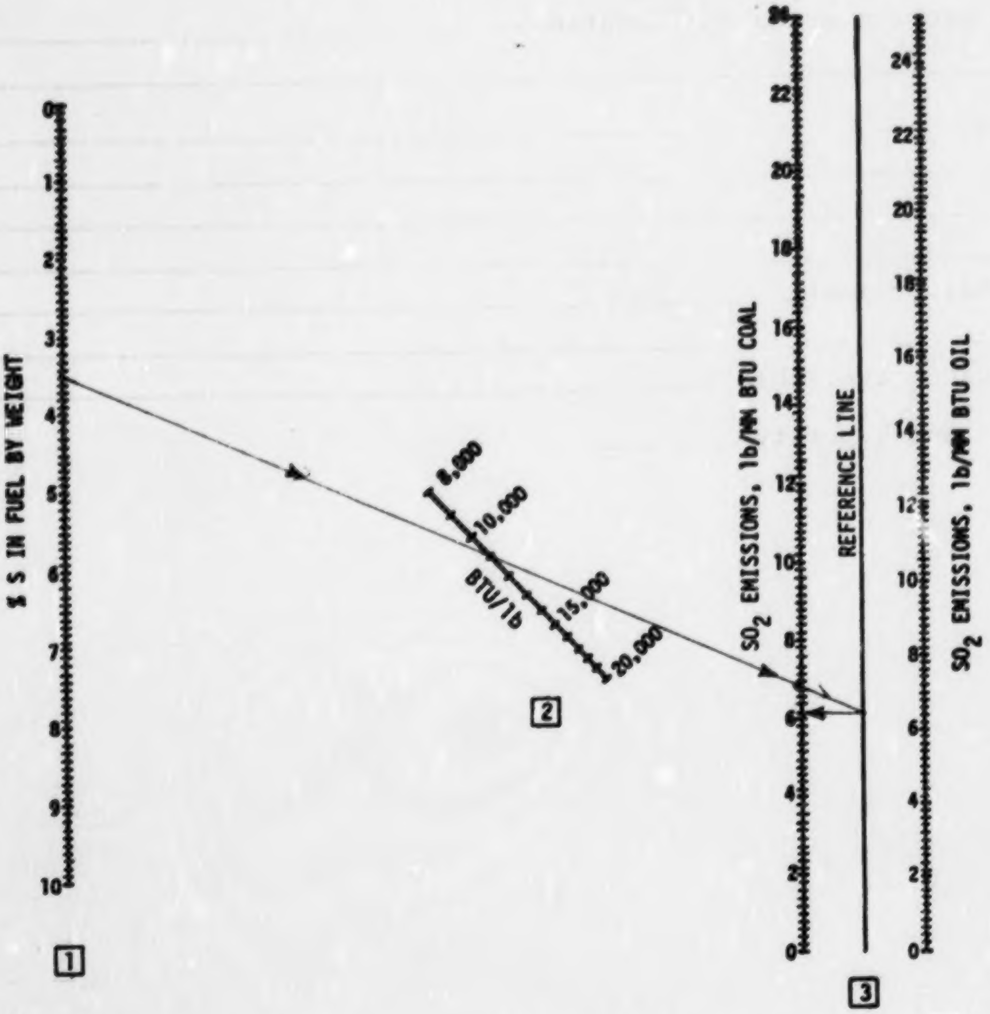


Chart 1. SO_2 EMISSION DETERMINATION

Assumptions:

(1) 95% of sulfur in coal converted to SO_2

(2) 100% of sulfur in oil converted to SO_2

SO_2 REMOVAL REQUIREMENTS

To calculate SO_2 emissions (lb/MM BTU) to be removed:

Enter from page B-4, Chart 1, item $\boxed{3}$ the lb/MM BTU ____________ $\boxed{3}$

Enter from the data sheet, allowable SO_2 emissions (lb/MM BTU) from the State or Federal regulations ____________ $\boxed{4}$

Subtract $\boxed{4}$ from $\boxed{3}$ to calculate SO_2 emissions (lb/MM BTU) to be removed ____________ $\boxed{5}$

LIMESTONE REQUIREMENTS

To determine the limestone requirements (lb/hr) and sulfur dioxide rate (lb/hr), Chart 2:

Enter the SO_2 emissions (lb/MM BTU) to be removed on item $\boxed{6}$ from page B-5, item $\boxed{5}$; record ____________ $\boxed{6}$

Enter stoichiometric* requirements for limestone on item $\boxed{7}$*

Connect $\boxed{6}$ and $\boxed{7}$ and extend to $\boxed{8}$ and read and record:

Limestone requirements (lb/MM BTU) ____________ $\boxed{8}$

Record from the data sheets the heat input (MM BTU/hr) ________ $\boxed{9}$

Multiply $\boxed{8}$ by $\boxed{9}$ and record:

Limestone requirements (lb/hr) ____________ $\boxed{10}$

Multiply $\boxed{6}$ x $\boxed{9}$ and record: lb SO_2/hr removed

____________ $\boxed{12}$

* If unknown, use 1.3.

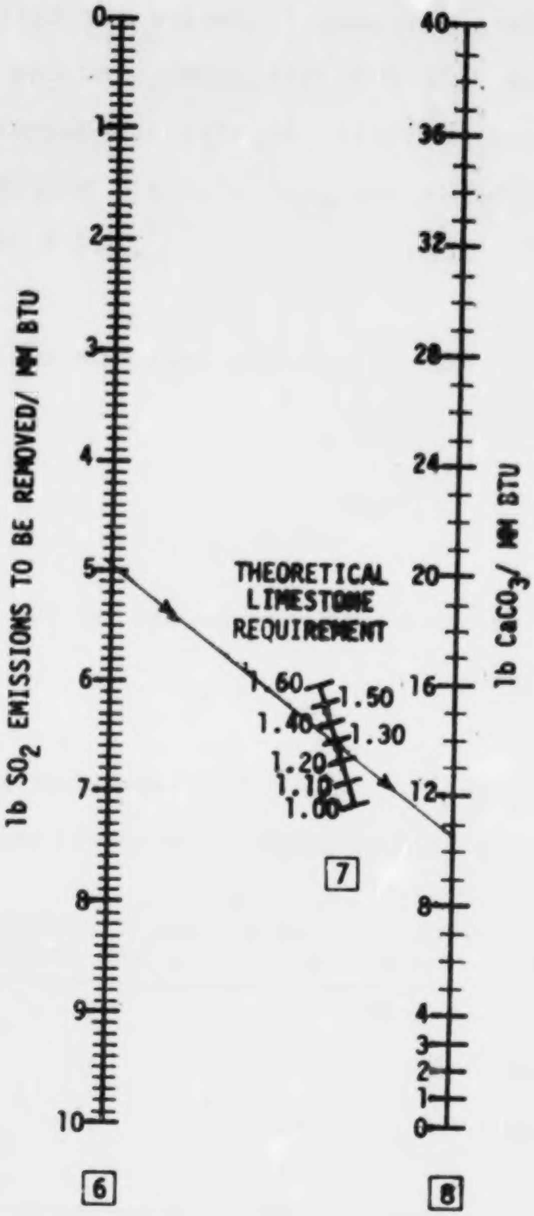


Chart 2. LIMESTONE REQUIREMENTS

FLY ASH EMISSION RATE CALCULATIONS FOR VENTURI DETERMINATION

To calculate fly ash emitted:

If the fly ash emitted (lb/MM BTU) in $\boxed{13}$ after passing through an existing particulate emission collector per boiler is greater than the allowable rate from the data sheet, the use of venturi is necessary. Use the following equation to calculate $\boxed{13}$

$$\boxed{13} = \left[\left(\frac{\%\ \text{ash in coal}^*}{100}\right)\left(\frac{\%\ \text{fly ash}^*}{100}\right)\left(1-\frac{\eta_c}{100}\right) \div \text{BTU/lb}\right] \times 10^6 = \text{lb/MM BTU}$$

$$= \left[0.\_\_\_\_\_)(0.\_\_\_\_\_)\ (1-0.\_\_\_)\ \div \_\_\_\_\_\_\right] \times 10^6 = \_\_\_\_\_\ \text{lb/MM BTU}$$

where

η_c = Efficiency of particulate emission collector system

BTU/lb = Heat value of fuel

% ash = from the data sheet

If fly ash removal is required for any or all of the units VENTURI COST CALCULATIONS will be used.

*If the percent of fly ash to ash is not known use the appropriate tabulated values for the boiler under consideration.

Type boiler - coal-fired	fly ash to ash, %
General pulverized	80
Dry bottom	85
Wet bottom	65
Cyclone	10

SLUDGE GENERATED

To determine the dry sludge (lb/hr) generated, item $\boxed{16}$, Chart 3:

From page B-8, item $\boxed{13}$ enter calculation of fly ash (lb/MM BTU)

______________ $\boxed{13}$

From page B-8, item $\boxed{5}$ enter lb SO_2/MM BTU ______________ $\boxed{5}$

From page B-7, Chart 2 item $\boxed{8}$ enter lb $CaCO_3$/MM BTU

______________ $\boxed{8}$

$\boxed{13} + \boxed{5} + \boxed{8} = \boxed{14}$ total dry sludge (lb/MM BTU)

______________ $\boxed{14}$

From data sheet, heat input maximum continuous rating, record here as (MM BTU/hr) ______________ $\boxed{15}$

Dry Sludge = $\boxed{14} \times \boxed{15} = \boxed{16}$ lb/hr

= __________ x __________ = __________ lb/hr $\boxed{16}$

$\boxed{16} \div 2000 =$ ______________ ton/hr $\boxed{16}$ A

Enter $\boxed{16}$ on $\boxed{17}$, Chart 3, enter ______ %* by weight dry sludge on $\boxed{18}$

Connect $\boxed{17}$ and $\boxed{18}$ and extend to $\boxed{19}$ and read:

Wet Sludge (lb/hr) = ______________ $\boxed{19}$

* If unknown, use 60%.

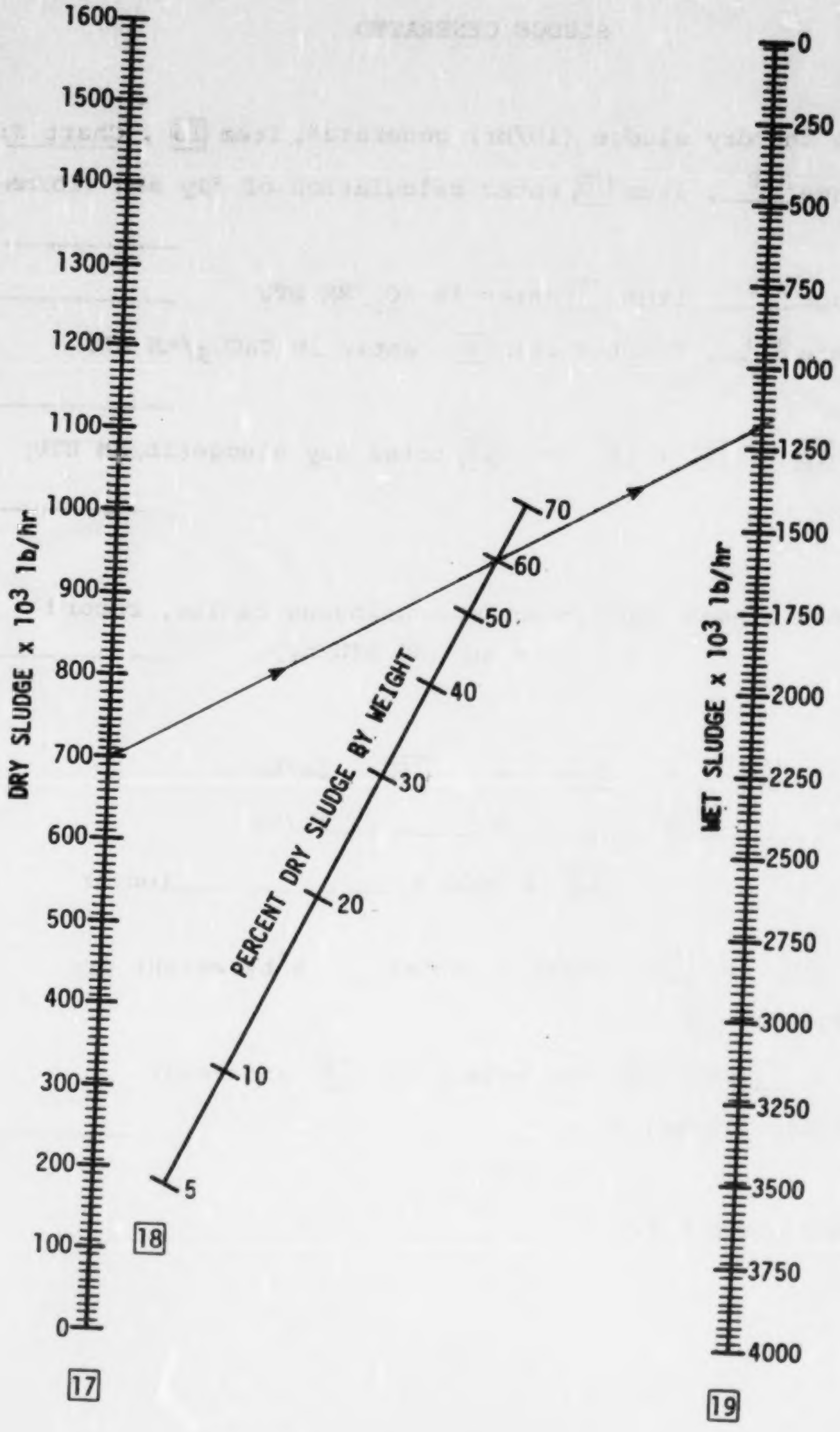


Chart 3. SLUDGE GENERATED

VENTURI AND ABSORBER COSTS

To determine the costs of venturi and absorber (including demister) using limestone, Chart 4:

First, determine number of scrubber trains -

Enter acfm at °F of flue gas from the data sheet on $\boxed{20}$, either per boiler or combined plant total if °F is the same for all boilers.

Enter temperature of flue gas (°F) on $\boxed{21}$

Connect $\boxed{20}$ and $\boxed{21}$ and extend to $\boxed{22}$ and read flue gas acfm at 125°C (saturated) and enter________acfm at 125°F and sat. $\boxed{22}$

If acfm at 125°F is greater than 375,000 divide $\boxed{22}$ by a number less than 375,000 to give a whole number of venturis and/or absorbers for each boiler.

acfm per venturi and/or absorber ____________ $\boxed{23}$

$$\frac{\underline{\qquad\qquad}\boxed{22}}{\boxed{23}} = \underline{\qquad\qquad}\boxed{24}$$

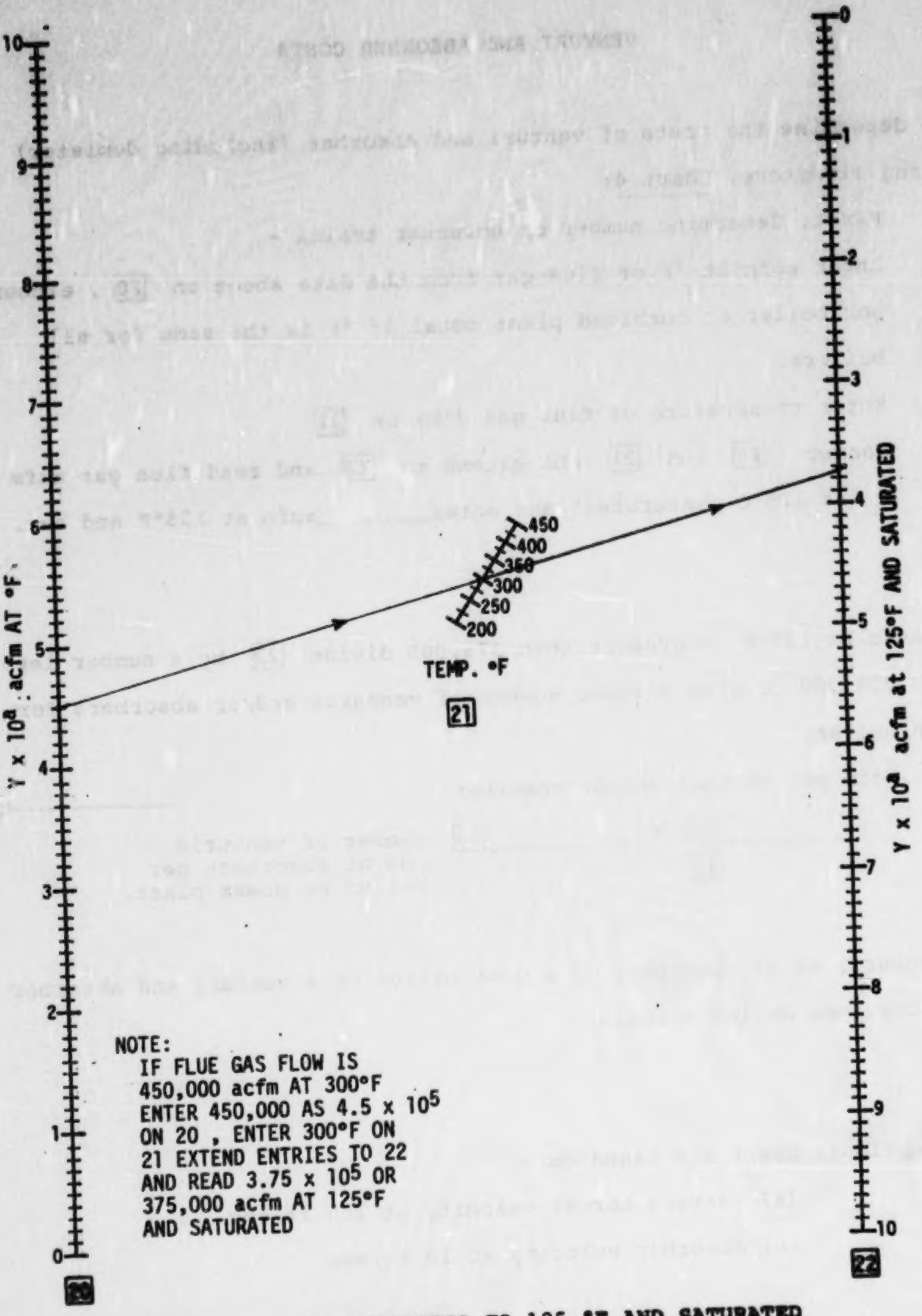
number of venturis and/or absorbers per boiler or power plant.

A venturi, or an absorber, or a combination of a venturi and absorber is sometimes called a train.

Assumptions: Costs are based on -

(a) Venturi throat velocity at 150 ft/sec

(b) Absorber velocity at 10 ft/sec


0
1
2
3
4
5
6
7
8
9
10
Y x 10⁵ acfm AT °F
20
450
400
350
300
250
200
TEMP. °F
21
0
1
2
3
4
5
6
7
8
9
10
Y x 10⁵ acfm at 125°F AND SATURATED
22

NOTE:
IF FLUE GAS FLOW IS 450,000 acfm AT 300°F ENTER 450,000 AS 4.5×10^5 ON 20, ENTER 300°F ON 21 EXTEND ENTRIES TO 22 AND READ 3.75×10^5 OR 375,000 acfm AT 125°F AND SATURATED

Chart 4. acfm CORRECTED TO 125 °F AND SATURATED

VENTURI AND ABSORBER COSTS

Then determine absorber costs (no venturi required) Chart 5:

Enter item $\boxed{22}$ from page B-12, Chart 4 on Chart 5 on $\boxed{25}$

Enter for the absorber the cost factor of 1.65 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read absorber cost

\$ ________________ $\boxed{27}_{A}^{*}$

Or determine venturi and absorber costs (if a venturi is required) Chart 5

Enter item $\boxed{22}$ from page B-12, Chart 4 on Chart 5 on $\boxed{25}$

Enter for the train the cost factor of 2.55 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read venturi and absorber costs \$ ________________ $\boxed{27}_{V+A}$

* To correct for velocity differential in absorber-

$\boxed{27}_{A} \times \frac{10\ \text{fps}}{\_\_\ \text{fps}} =$ \$________________ correct cost of absorber $\boxed{28}$

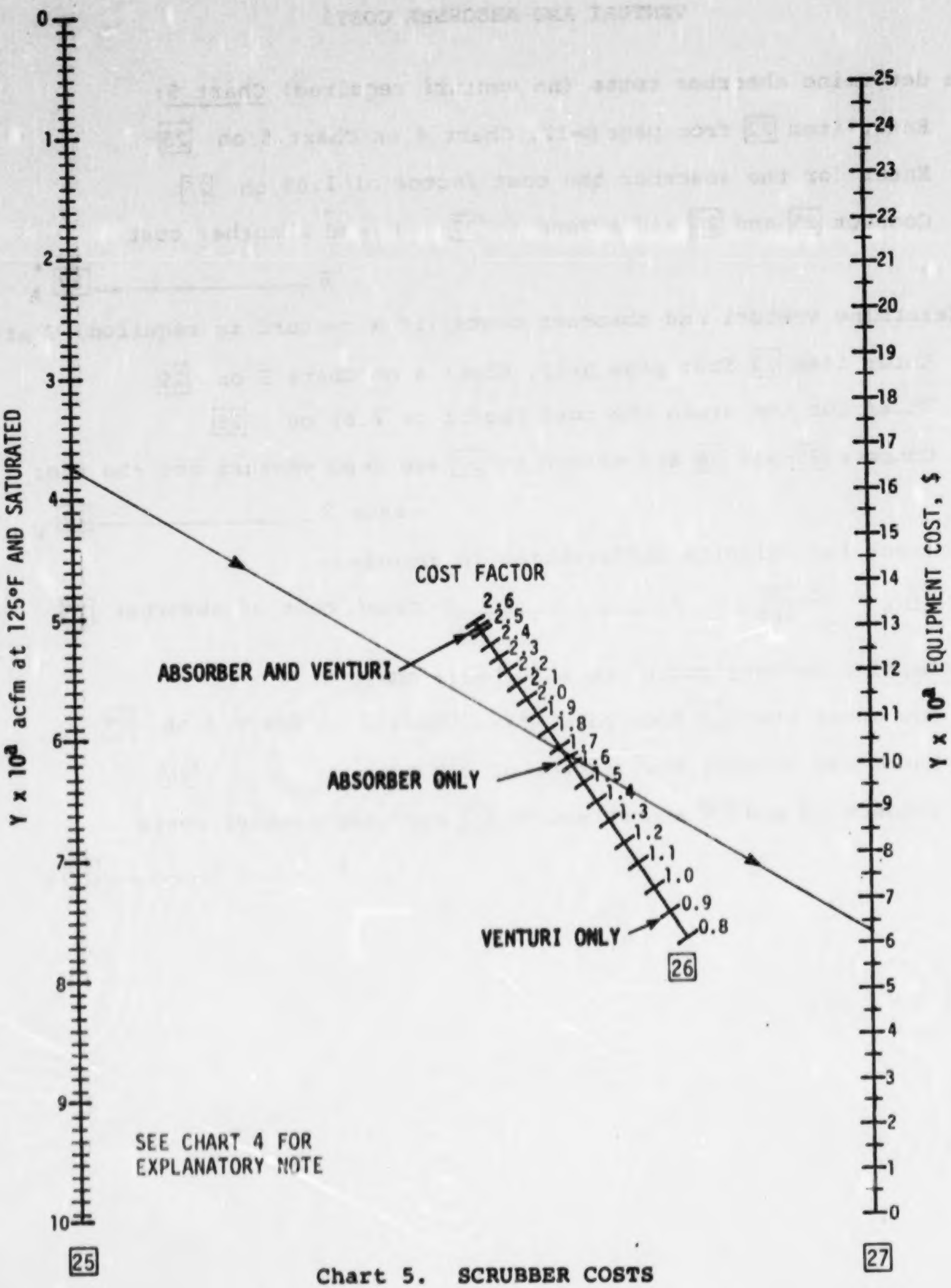
Or determine venturi costs (no absorber): Chart 5

Now enter item $\boxed{22}$ from page B-12, Chart 4 on Chart 5 on $\boxed{27}$

Enter the venturi cost factor of 0.9 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read venturi costs

\$ ________________ $\boxed{27}_{V}$



SEE CHART 4 FOR
EXPLANATORY NOTE

Chart 5. SCRUBBER COSTS

HOLDING TANK CAPACITY

To determine the holding tank capacity for absorber and/or venturi Chart 6:

Enter flue gas acfm from page B-12, Chart 4, Item $\boxed{23}$ on Chart 6, item $\boxed{29}$

Enter L/G*(liquid flow rate, gpm/1000 acfm at 125°F) on $\boxed{30}$

Connect $\boxed{29}$ and $\boxed{30}$ and extend to $\boxed{31}$, read and record:

Liquid flow rate (gal./min)__________ $\boxed{31}_A$ for absorber

Liquid flow rate (gal./min)__________ $\boxed{31}_V$ for venturi

Enter retention time on $\boxed{32}$

Select retention time:**

Connect $\boxed{31}$ and $\boxed{32}$ and extend to $\boxed{33}$, read and record:

Tank capacity (gal.) per absorber_______ $\boxed{33}_A$

(gal.) per venturi_______ $\boxed{33}_V$

* If unknown, use L/G = 65 for absorber and L/G = 15 for venturi

** If unknown, use 10 minutes for absorber and 4 minutes for venturi

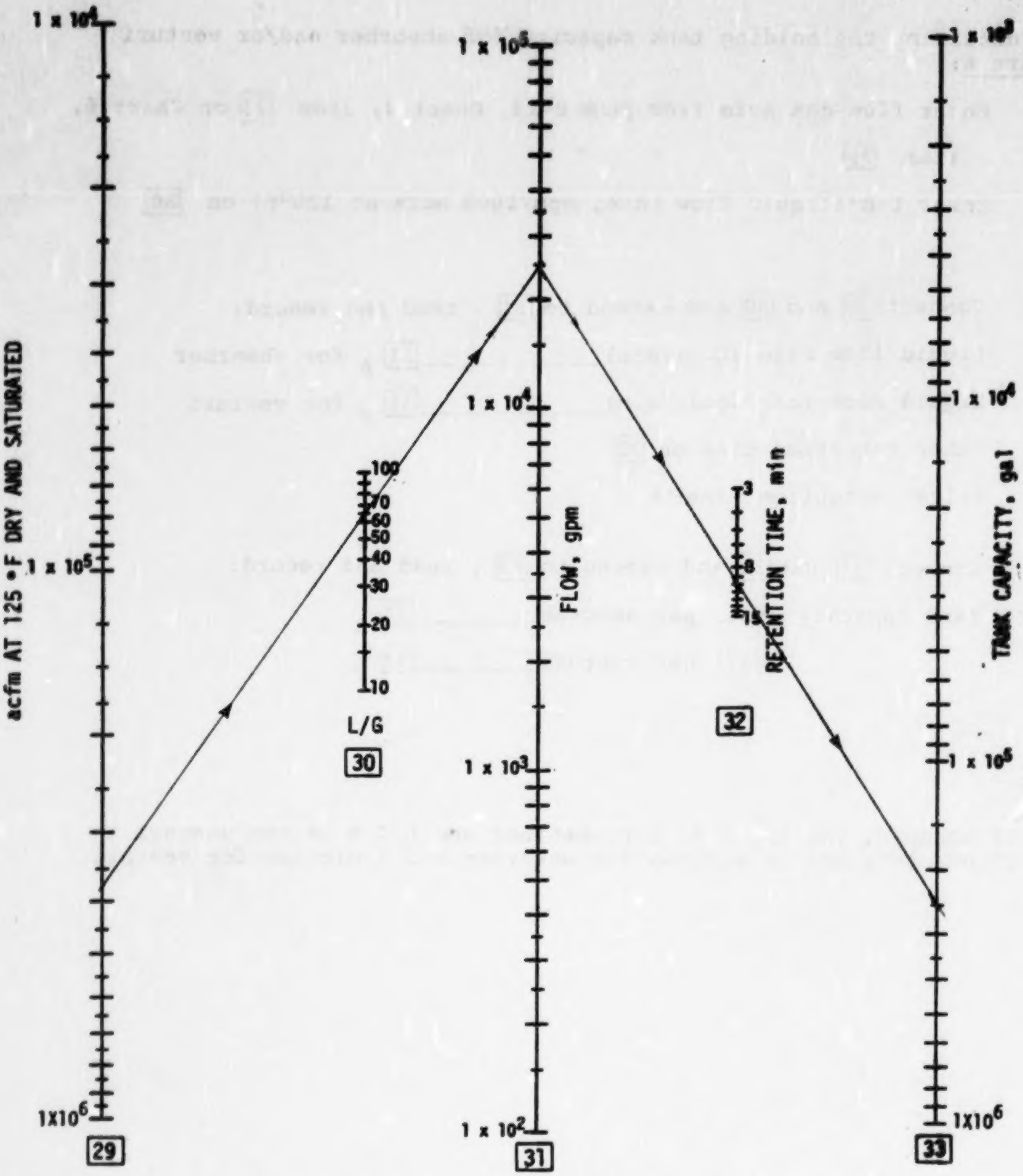


Chart 6. FLOW RATE AND TANK CAPACITY

HOLDING TANK AGITATOR COSTS

To determine the cost of agitators per tank, Table 7:

Compare tank capacity (gallons) from page B-16, Chart 6, item $\boxed{33}_A$ and/or $\boxed{33}_V$ on Table 7 under tank capacity in gallons column and record:

Cost of agitators per tank - absorber \$______________ $\boxed{34}_A$

venturi \$______________ $\boxed{34}_V$

Total cost of venturi and/or absorber:

($\boxed{34}_A$ + $\boxed{34}_V$) x No. of venturi or absorbers from item $\boxed{24}$

(__________ + __________) x ____________________ = \$__________.__________ $\boxed{35}$

Table 7. AGITATOR COST

Tank capacity, gal.	Agitators	
	No.	$\boxed{34}_A$ or $\boxed{34}_V$, cost, $
0 to 34,000	1	2,000
34,000 to 67,000	2	4,000
67,000 to 101,000	3	6,000
101,000 to 135,000	4	8,000
135,000 to 162,000	5	10,000
162,000 to 188,000	6	12,000
188,000 to 220,000	7	14,000
220,000 to 251,000	8	16,000
251,000 to 283,000	9	18,000

HOLDING TANK COSTS

To determine the tank cost the values in the chart are based on using $12.50/ft^2 for a field-fabricated, rubber-lined tank, Chart 8:

Enter tank capacity (gallons) on $\boxed{36}$ from page B-16, Chart 6, items $\boxed{33}_A$ and $\boxed{33}_V$, move vertically to $\boxed{37}$

From $\boxed{37}$ move horizontally to $\boxed{38}$, read and record:

Tank cost per absorber \$________________ $\boxed{38}_A$

Cost per venturi \$________________ $\boxed{38}_V$

Total Cost:

($\boxed{38}_A$ + $\boxed{38}_V$) x No. of absorbers $\boxed{24}$ = cost of holding tanks $\boxed{39}$

(_________+___________) x _____________ = \$______________________ $\boxed{39}$

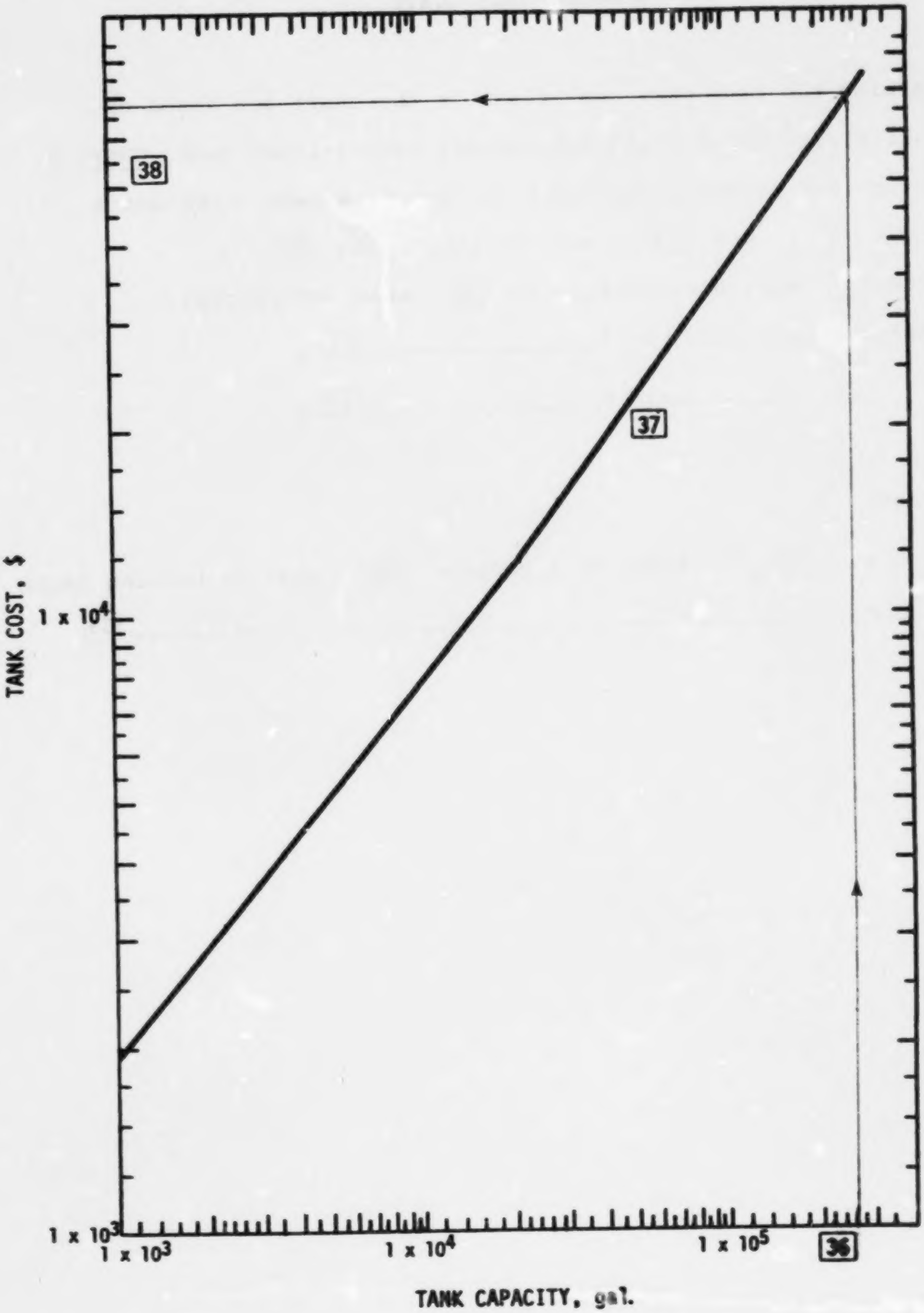


Chart 8. HOLDING TANK COSTS

HOLDING TANK PUMP COSTS

To determine the total pump cost for absorbers and/or venturi, Chart 9:

Enter gpm on $\boxed{40}$ from page B-16, Chart 6, item $\boxed{31}_A$ for the absorber and $\boxed{31}_V$ for the venturi. Select minimum number of pumps on $\boxed{41}$ (note 10,000 gpm per pump* is maximum), use minimum number of pumps per train and add 1 spare pump per tank.

Connect $\boxed{40}$ and $\boxed{41}$ and extend to $\boxed{42}$, read and record:

Flow rate (gpm) per pump ________ absorber; __________ venturi

Tabulate:	$\boxed{41}$ No. of pumps	$\boxed{42}$ gpm/pump	$\boxed{24}$ No. of trains
Absorber	____________	________	______________
Venturi	____________	________	______________

For total pump cost for venturi and/or absorber connect $\boxed{42}$ and enter $\boxed{41}$ on $\boxed{43}$ and extend to $\boxed{44}$, read and record:

Pump cost per tank \$__________ $\boxed{44}_A$ absorber; \$__________ $\boxed{44}_V$ venturi

*If gpm per pump is 5,000 or less calculate cost as follows:

Record gpm from page B-16, Chart 6, item $\boxed{31}_A$ for absorber ________ $\boxed{45}$

item $\boxed{31}_V$ for venturi ________ $\boxed{46}$

Number of trains from page B-11, item $\boxed{24}$ ____________

Number of pumps per tank 1 + 1 spare

Absorber pump costs:

$$2 \times (\ \boxed{45}\ ) \times (0.79) \times \boxed{24} = \boxed{47}_A$$

$$1.58 \times (\underline{\qquad\qquad}) \times \underline{\qquad\quad} = \$\,\underline{\qquad\qquad\qquad} \boxed{47}_A$$

HOLDING TANK PUMP COSTS (Continued).

Venturi pump costs:

$$2 \times (\ \boxed{46}\ ) \times (0.92) \times \boxed{24} = \boxed{47}_V$$

$$1.84 \times (\underline{\qquad\quad}) \times \underline{\qquad\quad} = \$\,\underline{\qquad\qquad\qquad} \boxed{47}_V$$

Pump costs, total: from calculation (1 to 5,000 gpm/pump)

$$\boxed{47}_V + \boxed{47}_A = \boxed{49}$$

$$\underline{\qquad\qquad\quad} + \underline{\qquad\qquad\quad} = \$\,\underline{\qquad\qquad\qquad} \boxed{49}$$

Pump costs, total: from Chart 9 (5001 to 10,000 gpm/pump)

$$\boxed{44}_V + \boxed{44}_A = \boxed{49}$$

$$\underline{\qquad\qquad\quad} + \underline{\qquad\qquad\quad} = \$\,\underline{\qquad\qquad\qquad} \boxed{49}$$

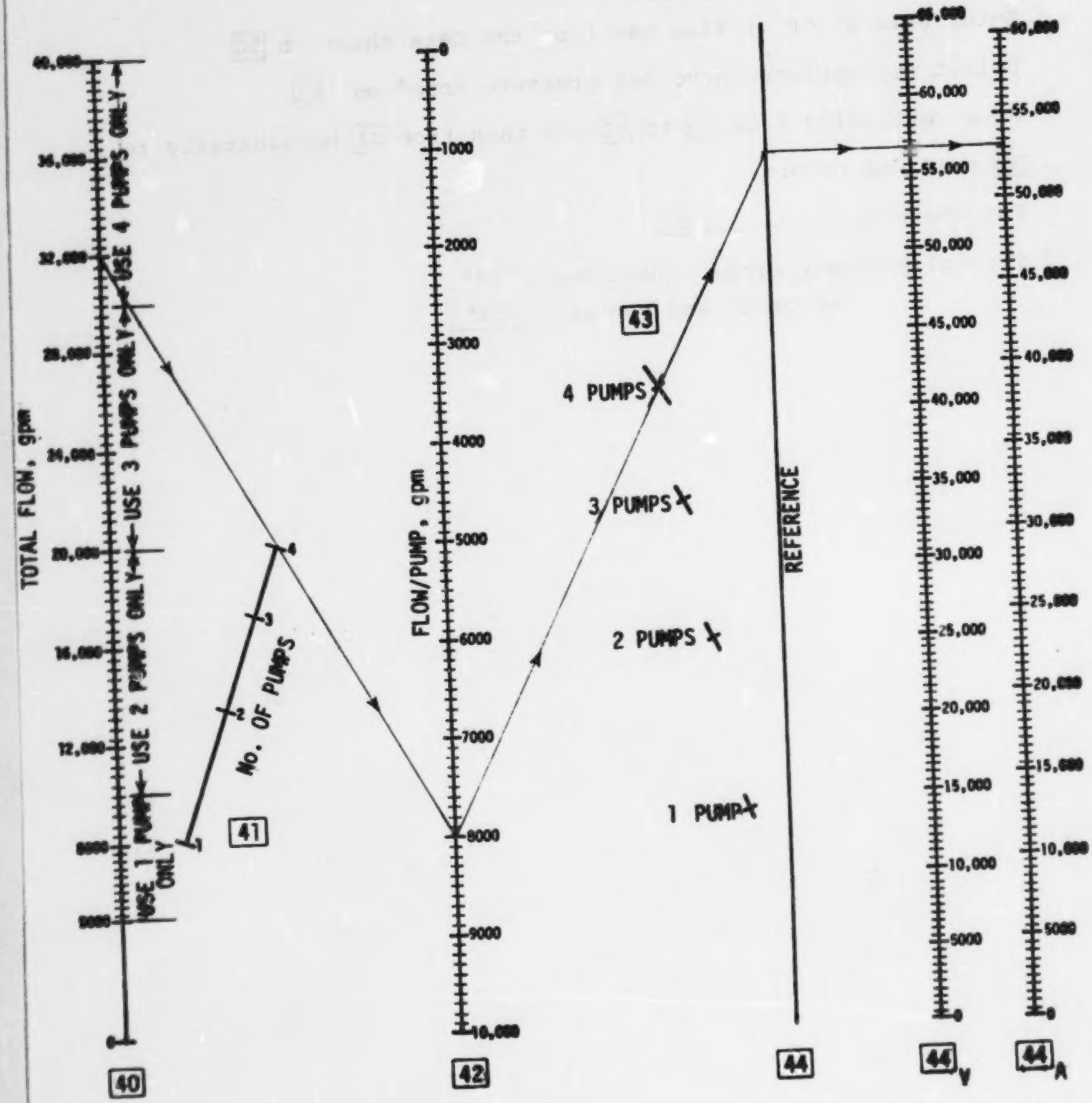


Chart 9. HOLDING TANK VARIABLE PUMP COSTS

FAN COSTS

To determine fan costs, Chart 10:

Enter acfm at °F of flue gas from the data sheet on $\boxed{50}$

Select appropriate curve for pressure drop* on $\boxed{51}$

Move vertically from $\boxed{50}$ to $\boxed{51}$ and then from $\boxed{51}$ horizontally to $\boxed{52}$ read and record:

Fan costs $ ____________ $\boxed{52}$

* Typical pressure drop: Absorber 18" ;
absorber and venturi 27"

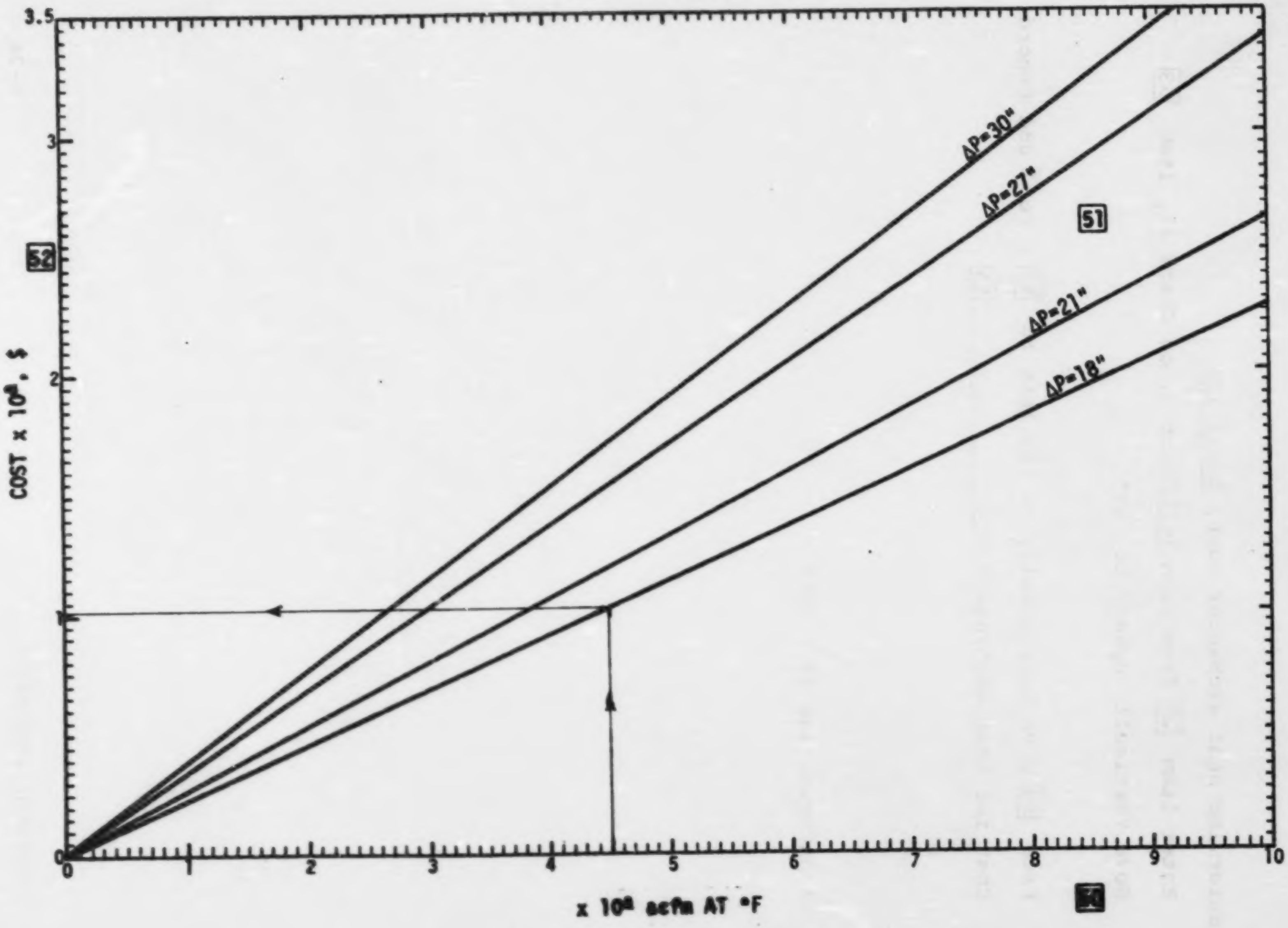


Chart 10. BOOSTER FAN COSTS

HEAT EXCHANGER COST

To determine heat exchanger cost, Chart 11:

Enter item $\boxed{22}$ from page B-12, Chart 4, on Chart 11, item $\boxed{53}$

Move vertically upward to ΔT*

From $\boxed{54}$ move horizontally to the left to $\boxed{55}$, read and record:

Cost for heat exchangers $______________ $\boxed{55}$

* If unknown, use $\Delta T = 50°F$

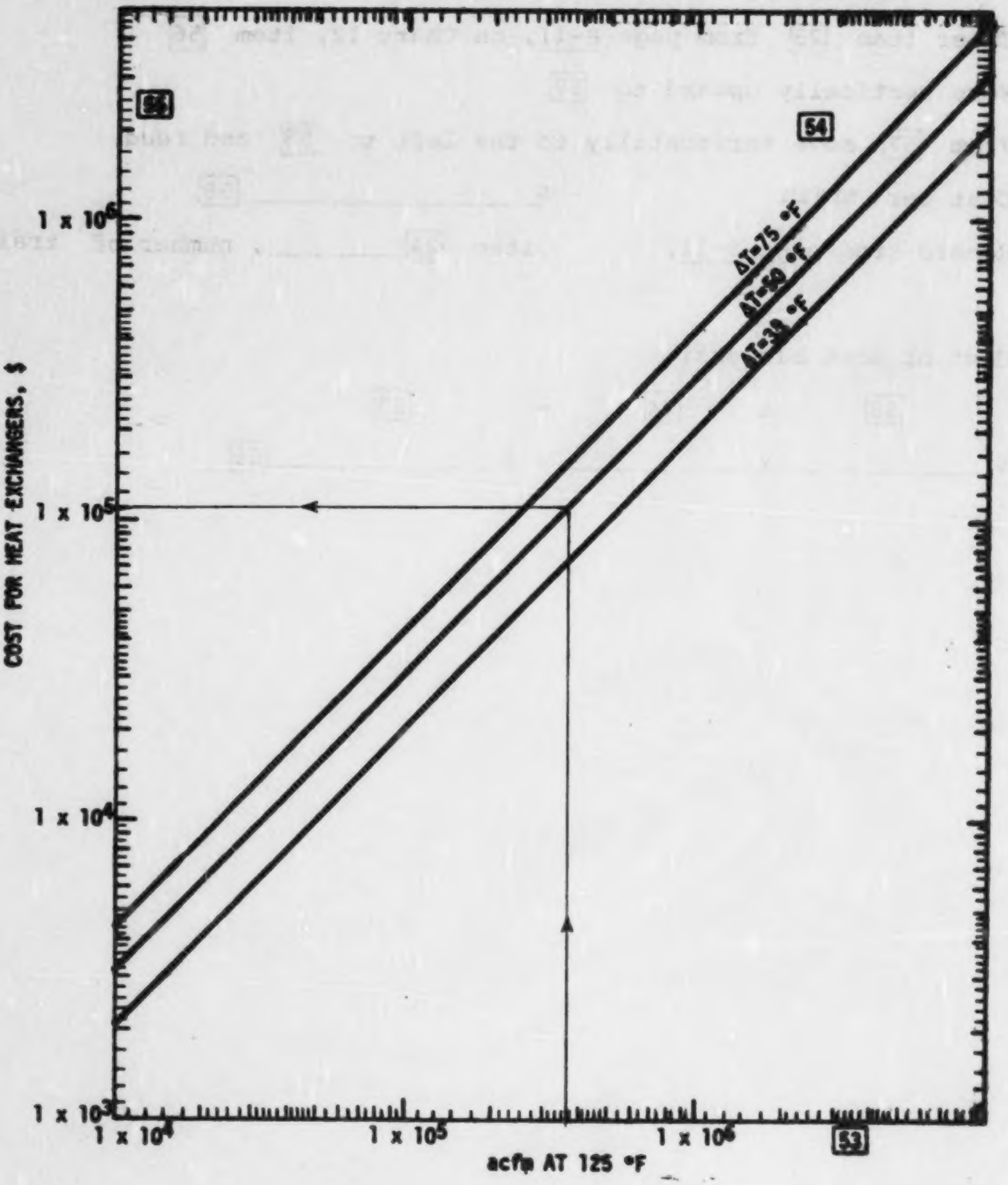


Chart 11. HEAT EXCHANGER COSTS

SOOT BLOWER COST

To determine soot blower cost, Chart 12:

Enter item $\boxed{23}$ from page B-11, on Chart 12, item $\boxed{56}$

Move vertically upward to $\boxed{57}$

From $\boxed{57}$ move horizontally to the left to $\boxed{58}$ and read:

Cost per train . $\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$ $\boxed{58}$

Record from page B-11, , item $\boxed{24}$ ________, number of trains

Cost of soot blowers:

$$\boxed{58} \quad \times \quad \boxed{24} \quad = \quad \boxed{59}$$

$\$\_\_\_\_\_\_\_\_\_\_ \times \_\_\_\_\_\_\_\_\_\_ = \$\_\_\_\_\_\_\_\_\_\_ \boxed{59}$

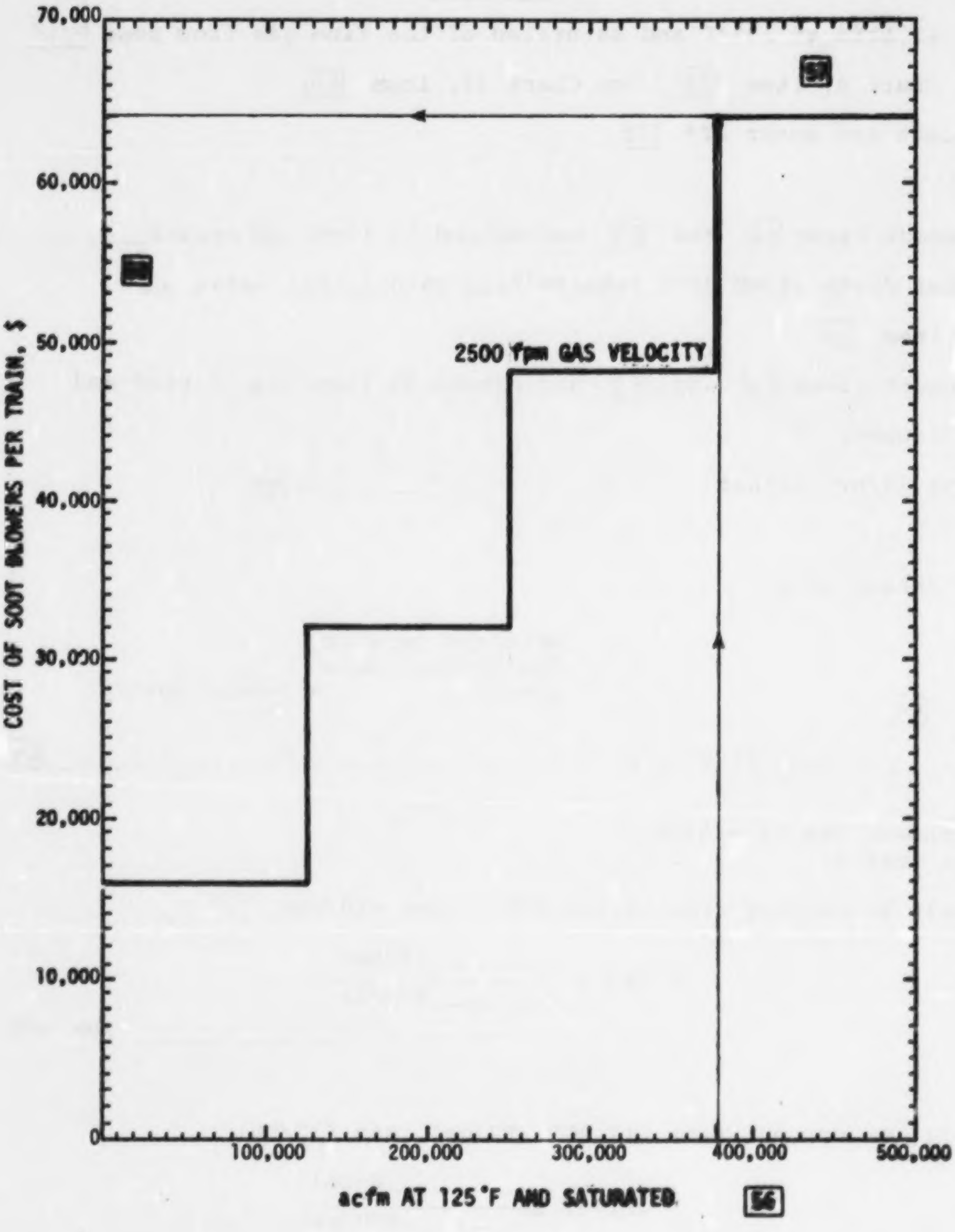


Chart 12. SOOT BLOWER COSTS

REHEAT COST

To calculate the cost of reheat, Chart 13:

Enter acfm at 125°F and saturated of the flue gas from page B-12 Chart 4, item $\boxed{22}$ on Chart 13, item $\boxed{60}$

Select and enter ΔT* $\boxed{61}$

Connect items $\boxed{60}$ and $\boxed{61}$ and extend to item $\boxed{62}$ record__________.

Enter costs ($/MM BTU) reheat** from calculation below, on item $\boxed{63}$

Connect items $\boxed{62}$ and $\boxed{63}$ and extend to item $\boxed{64}$, read and record:

Cost ($/hr) reheat ____________________ $\boxed{64}$

Annual reheat cost:

$$\underset{\$\_\_\_\_\_\_\_\_\_\_}{\boxed{64}} \times 8760 \text{ hr/yr} \times \underset{0.\_\_\_\_\_\_\_\_\_\_}{\text{Weighted capacity factor from data sheet}} = \underset{\$\_\_\_\_\_\_\_\_\_\_ \boxed{65}}{\text{reheat cost/yr}}$$

*If unknown, use ΔT = 50°F

**Reheat Cost -

Coal: To correct from 12,000 BTU/lb and $10/ton

$$= 665 \times \frac{\_\_\_\_\_\_\_\_\_\_(\$/\text{ton})}{\_\_\_\_\_\_\_\_\_\_\text{BTU/lb}}$$

$$= \$\_\_\_\_\_\_\_\_\_\_\_\_\_\_\text{/MM BTU}$$

Oil: To correct from 149,000 BTU/gal. and $10/bbl

$$= 31{,}707 \times \frac{\_\_\_\_\_\_\_\_\_\_(\$/\text{bbl})}{\_\_\_\_\_\_\_\_\_\_\text{BTU/gal.}}$$

$$= \$\_\_\_\_\_\_\_\_\_\_\_\_\_\_\text{/MM BTU}$$

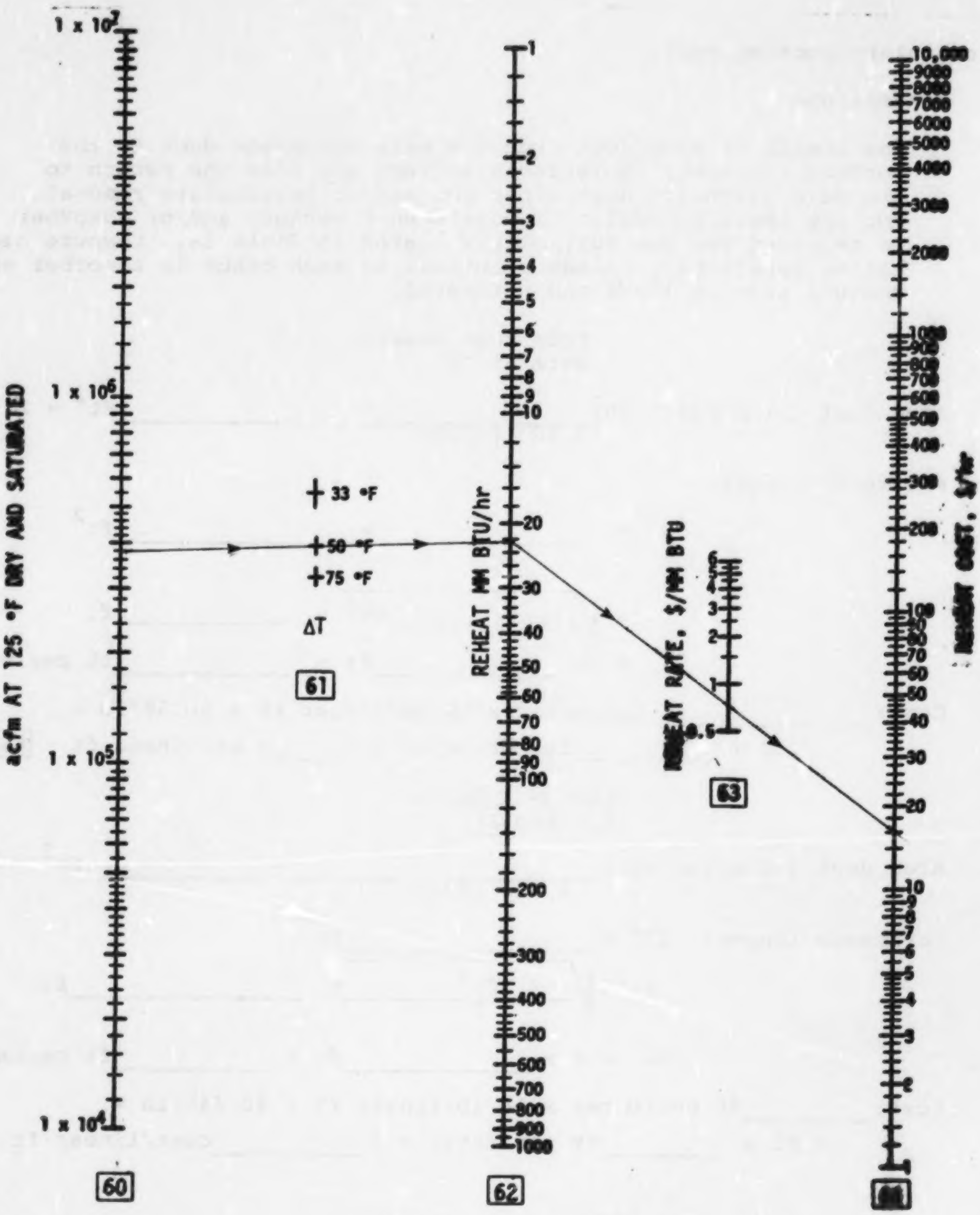


Chart 13. REHEAT COSTS

DUCT COSTS

To calculate ducting cost:

Assumption-

The length of flue duct from the main discharge duct to the venturi (if used) is variable in feet and also the return to the main discharge duct after SO_2 and/or particulate removal. For the specific boiler if more than 1 venturi and/or absorber is required use the multipliers listed in Table 14. Compute each boiler separately, unless identical to each other in absorber or venturi acfm at 125°F and saturated.

Area duct (from main) in: $\dfrac{\text{From data sheet, acfm at °F}}{3{,}500 \text{ ft/min}} = \underline{\hspace{3cm}} \text{ ft}^2 = 2\lambda^2$

Perimeter length:

$$\lambda^2 = \frac{\underline{\hspace{3cm}}}{2} = \underline{\hspace{3cm}} \text{ ft}^2$$

$$\lambda = \sqrt{\underline{\hspace{3cm}} \text{ ft}^2} = \underline{\hspace{3cm}} \text{ ft}$$

$$6\lambda = 6\times \underline{\hspace{3cm}} \text{ ft} = \underline{\hspace{3cm}} \text{ ft perimeter}$$

Cost: $\underline{\hspace{3cm}}$ ft perimeter x 18 lb/linear ft x \$0.39/lb =

7.02 x $\underline{\hspace{2.5cm}}$ ft perimeter = \$$\underline{\hspace{1.5cm}}$ cost/linear ft $\boxed{66}$

Area duct (to main) out: $\dfrac{\text{Page B-12 Chart 4, item } \boxed{22}}{2{,}500 \text{ ft/min}} = \underline{\hspace{3cm}} \text{ ft}^2 = 2\lambda^2$

Perimeter length: $2\lambda^2 = \underline{\hspace{4cm}} \text{ ft}$

$$\lambda = \sqrt{\frac{\underline{\hspace{1cm}} \text{ ft}^2}{2}} = \underline{\hspace{4cm}} \text{ ft}$$

$$6\lambda = 6\times \underline{\hspace{3cm}} \text{ ft} = \underline{\hspace{3cm}} \text{ ft perimeter}$$

Cost: $\underline{\hspace{2.5cm}}$ ft perimeter x 18 lb/linear ft x \$0.445/lb =

8.01 x $\underline{\hspace{2.5cm}}$ ft perimeter = \$$\underline{\hspace{3cm}}$ cost/linear ft $\boxed{67}$

DUCT COST

Table 14. MULTIPLIER FOR DUCT COST

No. of absorbers and/or venturis per boiler	Venturi and absorber in	Venturi or absorber only in	Venturi plus absorber out	Venturi or absorber only out
1	110	70	70	50
2	190	114	113	93
3	250	180	143	123
4	305	225	175	155
5	356	266	205	183
6	410	310	235	208
7	453	346	262	242
8	490	378	288	268
9	535	415	315	295
10	579	452	343	324

* Duct cost in -

(in) cost/linear ft x (Table 14 multiplier + Estimated ft to main duct-(30')) = Duct cost (in) 68

66 $__________ x (__________ + __________ -30) = $__________ 68

**Duct cost out -

(out) cost/linear ft x (Table 14 multiplier + Estimated distance to main duct -(50')) = Duct cost (out) 69

67 $__________ x (__________)+(__________ -50) = $__________ 69

Total duct cost -

68 duct cost (in) + 69 duct cost (out) = total duct cost 70

$__________ + $__________ = $__________ 70

* If congested area add 230 ft for estimated ft.

** If congested area add 200 ft for estimated ft.

LIMESTONE PREPARATION AREA COSTS

To calculate conveyor cost, Chart 15:

Estimate distance (ft) from storage pile area to sites and record

(ft) $\boxed{70}$ from storage pile area to silos

Record from page B-6 item $\boxed{10}$

____________ lb/hr $CaCO_3$

lb/hr $CaCO_3$ ÷ 2,000 = ____________ ton/hr $CaCO_3$ $\boxed{71}$

Enter ton/hr Chart 15 on $\boxed{71}$ and move vertically upward

to $\boxed{72}$ then move horizontally to the left

to $\boxed{73}$ and record $________ conveyor cost $\boxed{73}_C$

If $\boxed{70}$ is greater or less than 600 ft.

Enter ton/hr at $\boxed{71}$ and move vertically upward

to $\boxed{74}$ and then move horizontally to the left

to $\boxed{73}$ and record $________ conveyor cost/100 ft $\boxed{73}_D$

Number of 100 ft lengths that $\boxed{70}$ is greater or less than 600 ft ________ $\boxed{75}_D$

$\pm(\boxed{73}_D \times \boxed{75}_D) = \boxed{76}$ adjusted cost

±(________ x _______) = $ ________________ $\boxed{76}$

Conveyor cost:

$\boxed{73}_C \pm \boxed{76} = \boxed{77}$

____________ ± ____________ = $ ________ conveyor cost $\boxed{77}$

Assumptions:

Cost of the conveyor system installed: 2-inground hoppers, 2-15° incl. conveyors
(conveyor at 50' elev., conveyor covered , 2 trippers.)
Conveyor lengths: 2-300' inclined, 1-600' to silos, walkways.

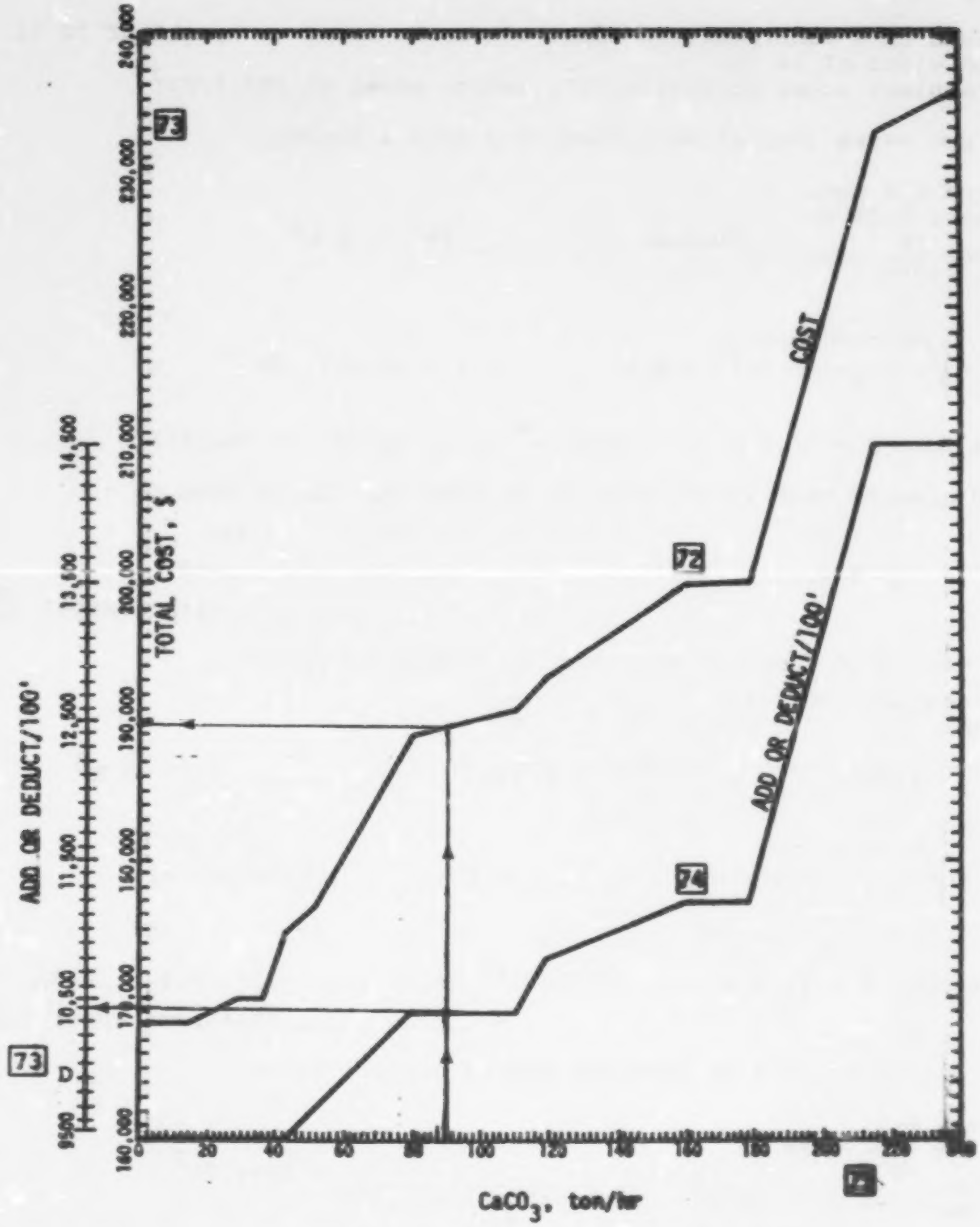


Chart 15. CONVEYOR COSTS

FLUE GAS SHUTOFF AND BYPASS VALVES

To calculate flue gas shutoff and bypass valve costs:

Assumption-

Based on 4 vanes/axis in short dimension based on height of 20 ft and width of 10 ft,
Stainless steel at \$141.6/ft^2; carbon steel at \$99.1/ft^2

Flue gas valve (in) at main duct to create a bypass

$$\frac{\text{From the data sheet acfm at } \_\_\_\_\,^\circ\text{F}}{3{,}500} \Big/ \text{Boiler} = \_\_\_\_\_\_\_\_\ \text{ft}^2 = 2\ W^2$$

$$W = \sqrt{\frac{\_\_\_\_\_\_}{2}\ \text{ft}^2}\,;\ W \times 2 = \_\_\_\_\_\_ \times 2 = \text{height, ft}$$

$$\text{Valve cost A} = (1.5 \times H)\ \ [(99.1) \pm^{*} (3.1)\ (H-20)\ (0.5H-10)]$$

*H greater than 20 ft, sign is +, less than 20 ft sign is -

$$= (1.5 \times \overset{(H)}{\_\_\_\_})\ \ [(99.1) \pm (3.1)\ (\overset{(H)}{\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_}-10)]$$

$$= \$\,\_\_\_\_\_\_\_\_\_\_\ \text{carbon steel}\quad \boxed{78}$$

Flue gas valve (out) at main duct to create a bypass

$$\frac{\text{Page B-12, Chart 4, item } \boxed{22}}{2{,}500} \Big/ \text{Boiler} = \frac{\boxed{22}}{2{,}500} = \_\_\_\_\_\_\_\_\ \text{ft}^2 = 2\ W^2$$

$$W = \sqrt{\frac{\_\_\_\_\_\_}{2}\ \text{ft}^2}\,;\ W \times 2 = \_\_\_\_\_\_ \times 2 = \_\_\_\_\_\_\ \text{ft (height H)}$$

$$\text{Valve cost B} = (1.5 \times \overset{(H)}{\_\_\_\_})\ \ [(141.6) \pm^{*} (4.5)\ (\overset{(H)}{\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_}-10)]$$

$$= \_\_\_\_\_\_\_\_\_\_\ \text{stainless steel}\quad \boxed{79}$$

Flue gas valve (in) to absorber and/or venturi train

$$\frac{\text{Page B-11 item } \boxed{23} \text{ acfm at } \_\_\_\_\,^\circ\text{F} \Big/ \text{Boiler}}{(\boxed{24}\ \text{No. of venturis or absorbers}) \times 3{,}500} = \text{Area, ft}^2$$

FLUE GAS SHUTOFF AND BYPASS VALVES (continued)

$$\frac{\boxed{23}\underline{\hspace{6em}}}{\boxed{24}\underline{\hspace{4em}} \times 3{,}500} = \underline{\hspace{8em}} = \text{Area, ft}^2 = 2\,W^2$$

$$W = \sqrt{\frac{\underline{\hspace{4em}}}{2}\ \text{ft}^2}\text{; } W \times 2 = \underline{\hspace{8em}}\ \text{Height (H), ft}$$

Valve cost C

$$= (\text{Height (H)} \pm 0.5\ \text{Height (H)}\ \big[(99.1)-(3.1)(H-20)\ (0.5H-10)\big]$$

$$= (1.5 \times \overset{(H)}{\underline{\hspace{3em}}})\ \big[(99.1)-(3.1)\ (\overset{(H)}{\underline{\hspace{3em}}}-20)\ (0.5\overset{(H)}{\underline{\hspace{3em}}}-10)\big]$$

$$= \underline{\hspace{8em}}\ \text{carbon steel} \qquad \boxed{80}$$

Valve cost D =

$$\left(\frac{\text{Page }\underline{\text{B-14}}\text{, Chart 4, item }\boxed{24}}{\text{No. of venturis and/or absorbers}}\right) \times (\text{valve cost}_C\ \boxed{80}) = \qquad \boxed{81}$$

$$= (\underline{\hspace{6em}}) \times (\underline{\hspace{8em}}) = \$\underline{\hspace{10em}}\boxed{81}$$

Flue gas valve (out) from absorber and/or venturi

$$\frac{\text{Page }\underline{\text{B-11}}\text{, item }\boxed{23}}{\dfrac{1.08\ \text{acfm at 175°F}}{2{,}500}} \Big/ \text{Venturi and/or absorber} = \text{ft}^2$$

$$0.000432 \times \overset{\boxed{23}}{\underline{\hspace{6em}}} = \underline{\hspace{6em}}\ \text{ft}^2 = 2\,W^2$$

$$W = \sqrt{\frac{\underline{\hspace{4em}}}{2}\ \text{ft}^2}\text{; } W \times 2\underline{\hspace{5em}} \times 2 = \underline{\hspace{7em}}\ \text{ft, (H)}$$

Valve cost_E =

$$= (1.5\overset{(H)}{\underline{\hspace{4em}}})\ \big[(141.6)-(4.5)\ (\overset{(H)}{\underline{\hspace{4em}}}-20)\ (0.5\overset{(H)}{\underline{\hspace{4em}}}-10)\big]$$

$$= \$\underline{\hspace{10em}}\ \text{stainless steel}\ \boxed{82}$$

Valve cost_F =

$$\left(\frac{\text{Page }\underline{\text{B-11}}\text{, item }\boxed{24}}{\text{No. of venturis and/or absorbers}}\right) \times (\text{valve cost}_E\ \boxed{82}) = \qquad \boxed{83}$$

$$= (\underline{\hspace{6em}}) \times (\underline{\hspace{8em}}) = \$\underline{\hspace{8em}}\boxed{83}$$

Valving cost per boiler

$$\text{Valve cost}_G = \boxed{78} + \boxed{79} + \boxed{81} + \boxed{83} = \boxed{84}$$

$$= V_A \qquad V_B \qquad V_D \qquad V_F$$

$$= \underline{\hspace{5em}} + \underline{\hspace{5em}} + \underline{\hspace{5em}} + \underline{\hspace{5em}}$$

$$= \$\underline{\hspace{10em}}\ \text{total valve cost} \qquad \boxed{84}$$

BALL MILL COSTS

To calculate ball mill costs and horsepower (hp), Chart 16:

From page B-31, Chart 15, item 71 ____________ ton/hr $CaCO_3$

$\boxed{71}$ x 1.2 (excess capacity) = Ball mill capacity

_________ x 1.2 = _________________ ton/hr ball mill capacity $\boxed{85}$

If $\boxed{85}$* is less than 100 ton/hr, $\boxed{85}$ ÷ 2 = ton/hr/ball mill $\boxed{86}$

__________ ÷ 2= ______ ton/hr/ball mill $\boxed{86}$

Enter $\boxed{86}$ or $\boxed{93}$ on Chart 16 on $\boxed{87}$ and move vertically upward

to $\boxed{88}$ then horizontally to the left

to $\boxed{89}$ and read: \$__________/ball mill

$\boxed{89}$ x No. of ball mills from $\boxed{85}$ = total cost of ball mill $\boxed{90}_T$

_________ x( ) = \$________ total ball mill cost $\boxed{90}_T$

Horsepower of ball mill:

Enter $\boxed{86}$ or $\boxed{93}$ on Chart 16 on $\boxed{87}$ and move vertically upward

to $\boxed{90}$ then horizontally to the right

to $\boxed{91}$ and read: __________ hp/ball mill $\boxed{91}$

$\boxed{91}$ x No. of ball mills from $\boxed{85}$ = total ball mill hp $\boxed{92}$

_________ x ( ) = __________ total hp $\boxed{92}_T$

*If $\boxed{85}$ is greater than 100 ton/hr, select capacity to be less than 50 ton/hr per ball mill and equal capacities

$\boxed{85}$ ÷ (minimum No. of ball mills with capacities under 50 ton/hr) = $\boxed{93}$

$\boxed{85}$

___________ ÷ (_____________) = ton/hr $\boxed{93}$

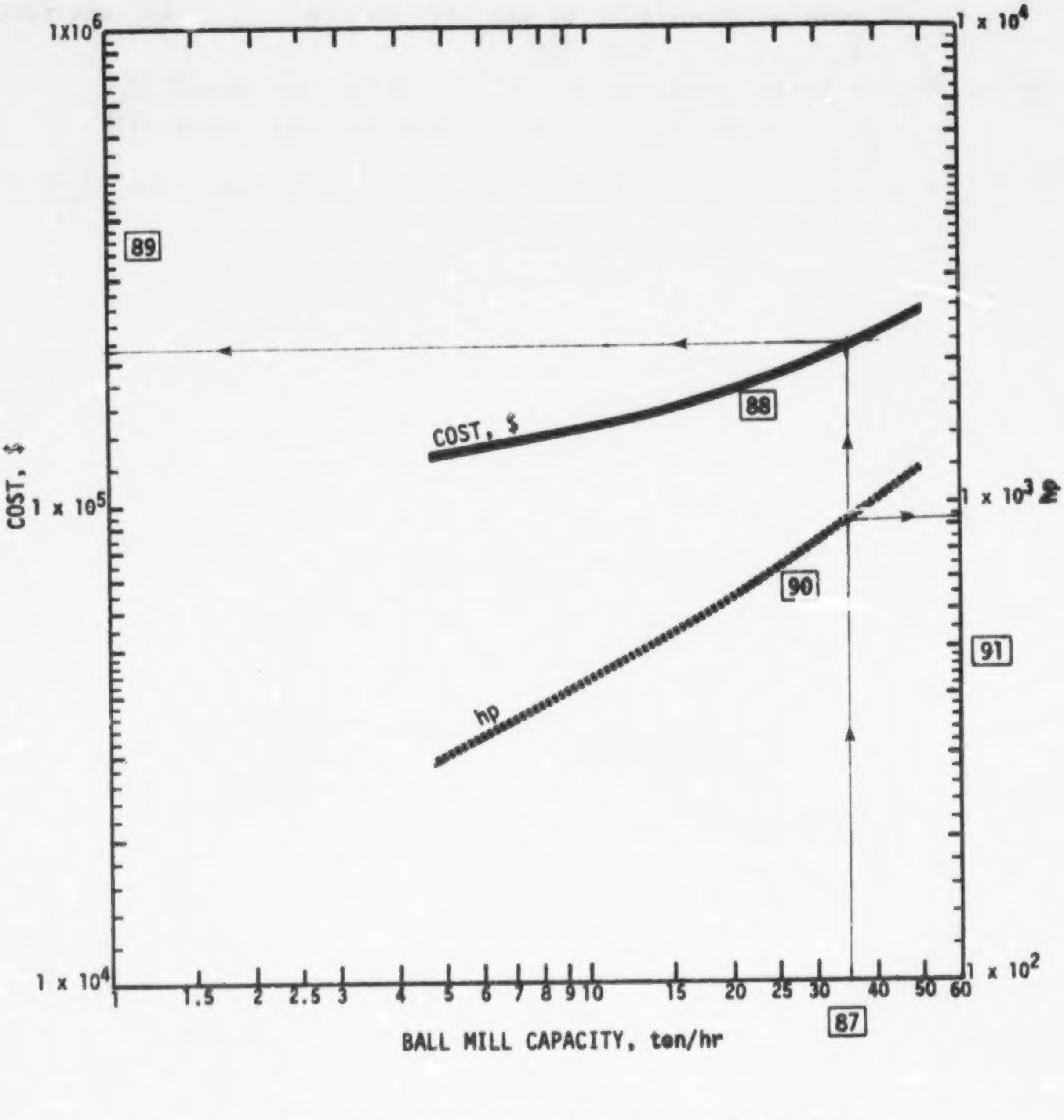


Chart 16. BALL MILL COSTS AND HORSEPOWER

BALL MILL TANK AND PUMPS

To calculate costs of ball mill tank and pumps, Chart 17:

Enter item $\boxed{71}$ from page B-31, Chart 15 on Chart 17, item $\boxed{94}$ then move vertically upward to item $\boxed{95}$ then move horizontially to the left to item ______ $\boxed{96}$ and read:

$ ____________ tank $\boxed{96}$

$\boxed{96}$ x [No. of tanks (equal to No. of ball mills from page B-38, item $\boxed{85}$)] = total tank and pump costs $\boxed{97}$

__________ x [________] = $ ______________ total tank cost $\boxed{97}$

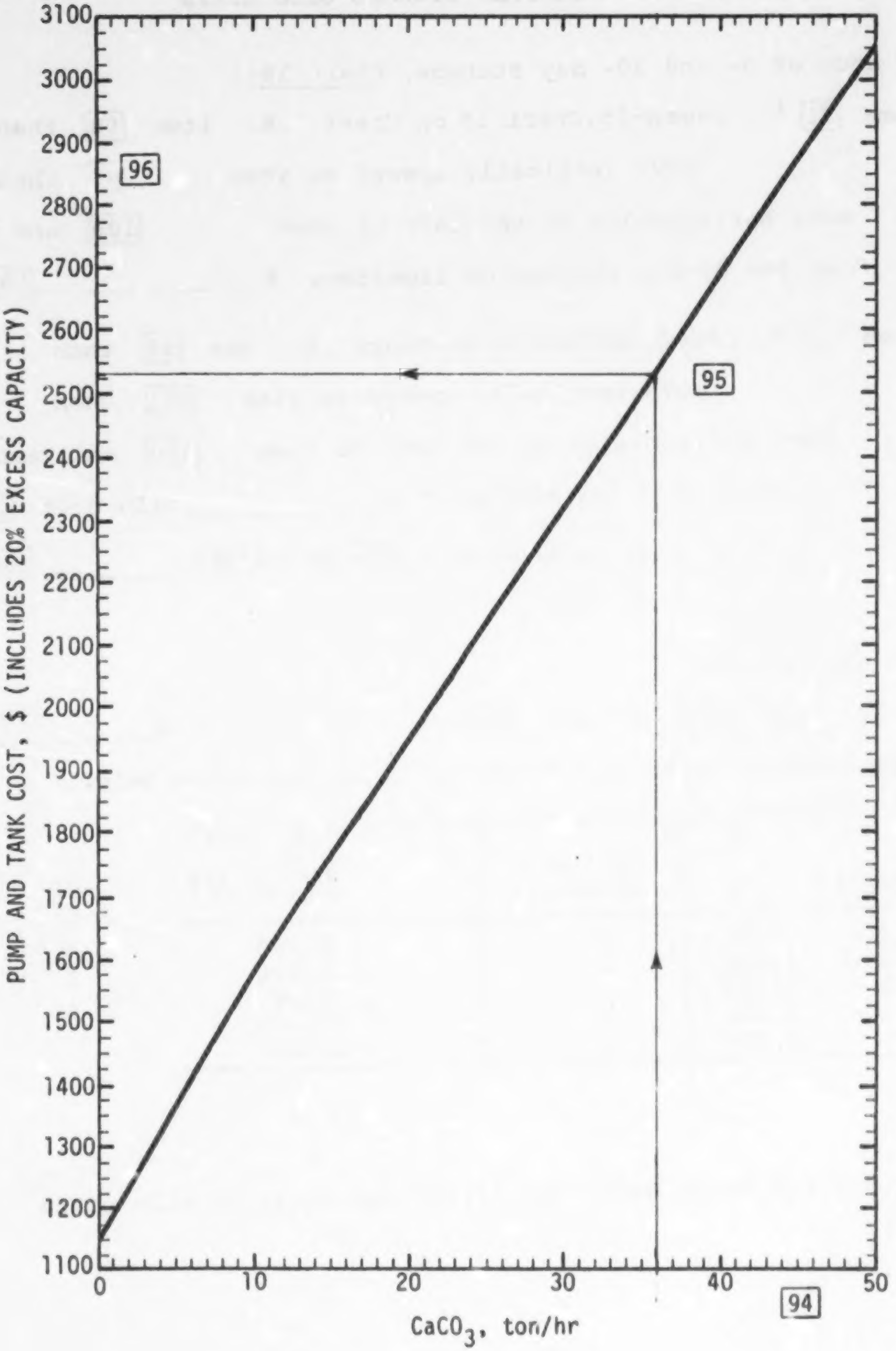


Chart 17. **BALL MILL AND PUMP COSTS**

LIMESTONE STORAGE AND FIXATION STORAGE SILO COSTS

To calculate cost of 3- and 30- day storage, Chart 18:

Enter item $\boxed{71}$ *, page B-35, Chart 15 on Chart 18, item $\boxed{98}$ then
move vertically upward to item $\boxed{99}$ then
move horizontally to the left to item $\boxed{100}$ and read
Cost for 30-day storage of limestone $______________ $\boxed{100}_{ST}$

Enter item $\boxed{71}$ *, page B-35 Chart 15 on Chart 18, item $\boxed{98}$ then
move vertically upward to item $\boxed{101}$ then
move horizontally to the left to item $\boxed{100}$ and read
Cost of 3 day storage = $____________ silo cost $\boxed{100}$

Total cost of storage = $\boxed{100}_{ST}$ + $\boxed{100}$ = ________ $\boxed{100}_{S}$

** Fixation silo cost -

1/3 x item $\boxed{100}_{S}$ = cost $\boxed{101}$ = 0.33 x______ = $__________ $\boxed{101}$

* If tonnage usage is under 8.3 ton/hr of $CaCO_3$ use table below

lb/hr	No. of silos	$\boxed{100}_{S}$ cost/ ancilliary equipment
0 - 500	1	4,000
501 - 2,000	1	5,000
2001 - 5,000	1	9,000
5001 - 10,000	2	20,000
10001 - 16,600	2	23,000

** Under 8.3 ton/hr of $CaCO_3$ use $9,000 for fixation silo costs

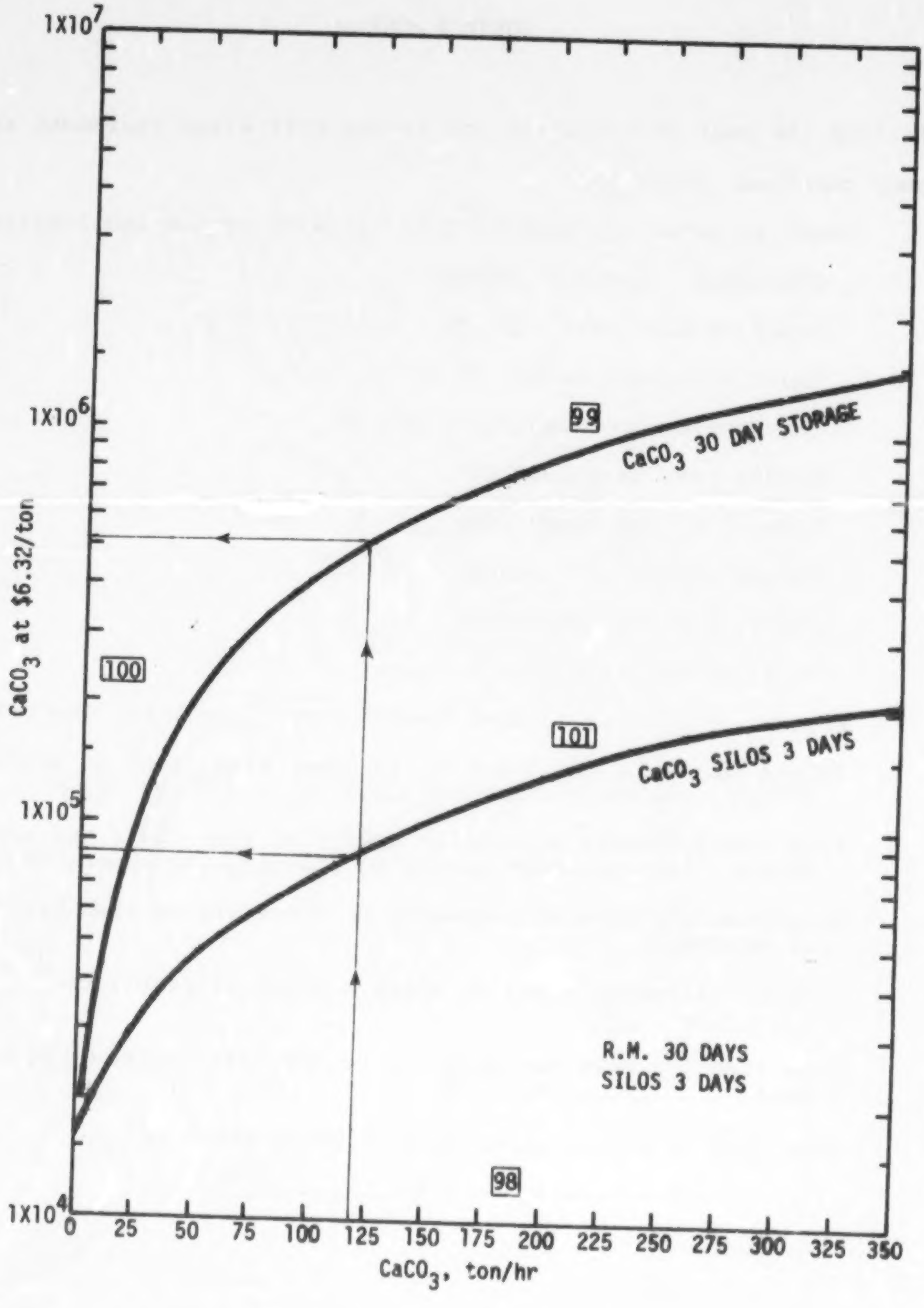


Chart 18. LIMESTONE STORAGE COST

SOLID DISPOSAL

To find the cost of clarifier and vacuum filtration equipment and pump combined, Chart 19:

Chart 19 gives the cost of the following system and limitations:

Clarifier, 150 ft diameter

Overflow pump head, 250 ft

Under flow pump head, 250 ft

Filtrate-return pump head, 350 ft

Sludge pump head 1000 ft

Under flow emergency pump

Vacuum filter, 50 ton/hr

Sludge mix tank and mixer

Water make-up pump

Enter item $\boxed{16}$ (dry sludge, ton/hr), from page B-19, Chart 3 on item 10

Select number of clarifier units, same size (each 50 ton/hr of dry sludge requires 1 clarifier unit) = ______units $\boxed{103}$

From item $\boxed{102}$ move vertically upward to item $\boxed{104}$ (Bhp system curve), then continue upward to item $\boxed{105}$ (equipment cost curve).

From item $\boxed{104}$ move horizontally to the right to item $\boxed{106}$ for hp of equipment.

hp of equipment x No. of units = total hp required= $\overset{\boxed{106}}{\_\_\_\_\_\_}$ x $\overset{\boxed{103}}{\_\_\_\_\_\_}$ = ________hp $\boxed{107}$

From item $\boxed{105}$ move horizontally to the left to item $\boxed{108}$ for equipment, $_________/unit $\boxed{108}$

Item $\boxed{108}$ x No. of units $\boxed{103}$ = total cost $\boxed{109}$

_________x_______________= $_________ $\boxed{109}$

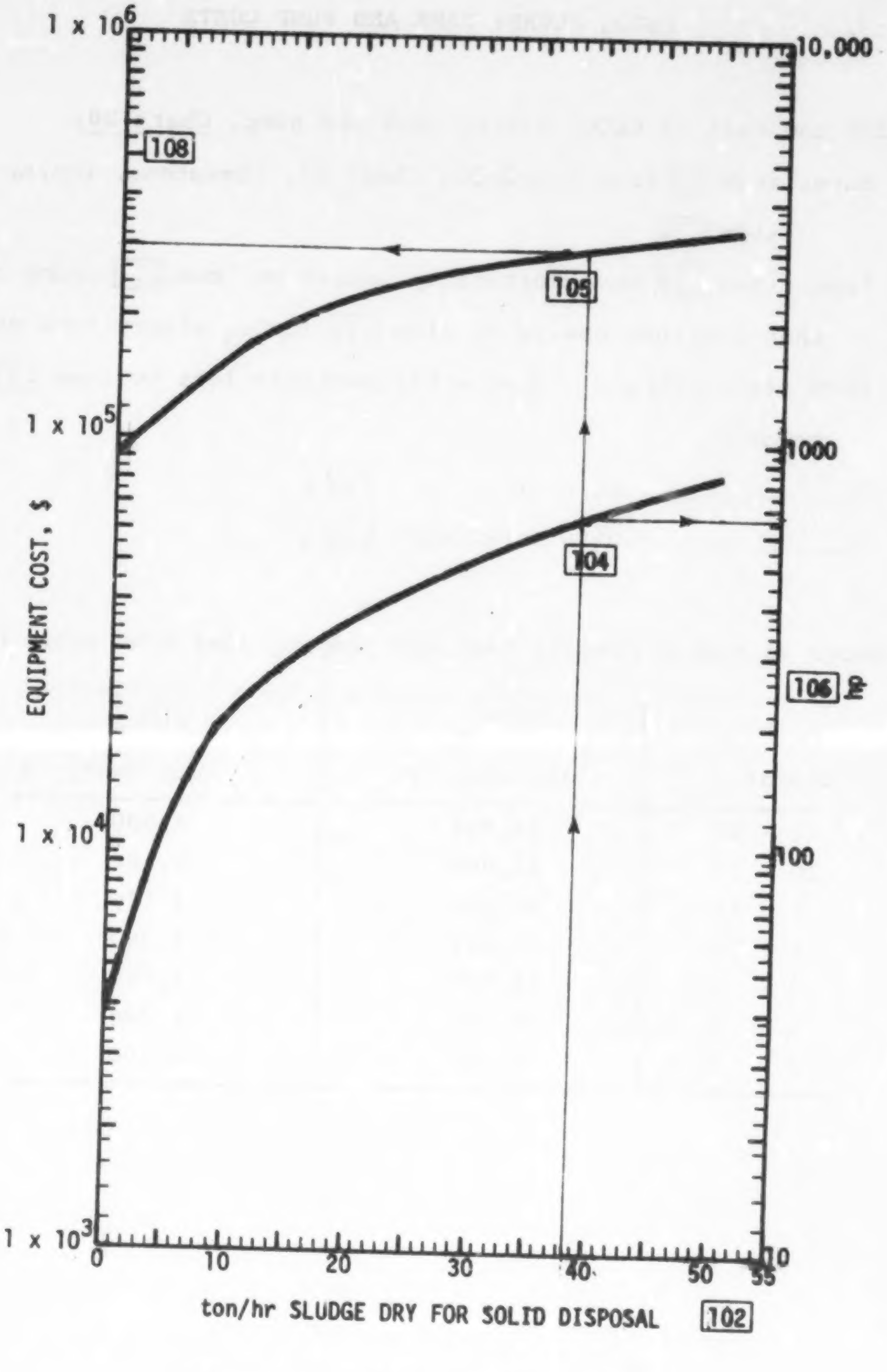


Chart 19. SOLID DISPOSAL COSTS

$CaCO_3$ SLURRY TANK AND PUMP COSTS

To find the cost of $CaCO_3$ slurry tank and pump, Chart 20:

Enter item $\boxed{71}$* from page B-35, Chart 15, limestone, ton/hr on Chart 20 item $\boxed{110}$

From item $\boxed{110}$ move vertically upward to item $\boxed{111}$ (pump cost curve), then continue upward to item $\boxed{112}$ ($CaCO_3$ slurry tank curve).

From items $\boxed{111}$ and $\boxed{112}$ move horizontally left to item $\boxed{113}$ read and record:

$__________ pump cost $\boxed{113}_P$

$__________ slurry tank cost $\boxed{113}_T$

* Under 15 ton/hr compute tank and pumping cost from table below

ton/hr	$\boxed{113}_T$ Tank cost, $	$\boxed{113}_P$ Pump Cost, $
13 - 15	36,000	6,000
10 - 13	32,000	5,100
7 - 10	26,000	4,100
5 - 7	20,000	3,200
3 - 5	16,000	2,500
1 - 3	10,000	1,700
0 - 1	5,000	1,200

$CaCO_3$ SLURRY TANK AND PUMP COSTS

Table for mixers -

Select ton/hr of $CaCO_3$ and corresponding cost of mixers:

ton/hr $CaCO_3$	Mixer cost, $	ton/hr $CaCO_3$	Mixer cost, $
0 12.6	2,000	187.5 - 201.6	32,000
12.6 - 25.2	4,000	201.6 - 226.8	36,000
25.2 - 37.8	6,000	226.8 - 252.0	40,000
37.8 - 50.4	8,000	252.0 - 277.4	44,000
50.4 - 63.0	10,000	277.4 - 302.4	48,000
63.0 - 75.6	12,000	302.4 - 327.6	52,000
75.6 - 88.2	14,000	327.6 - 352.8	56,000
88.2 -100.8	16,000	352.8 - 375.0	60,000
100.8 -113.4	18,000		
113.4 -126.0	20,000		
126.0 -138.6	22,000		
138.6 -151.2	24,000		
151.2 -163.8	26,000		
163.8 -176.4	28,000		
176.4 -187.5	30,000		

$______________ mixer cost $\boxed{113}_M$

Total cost:

$$\boxed{113}_P + \boxed{113}_T + \boxed{113}_M = \boxed{114}$$

$________________ + $______________ + $____________ =

$____________________ $\boxed{114}$

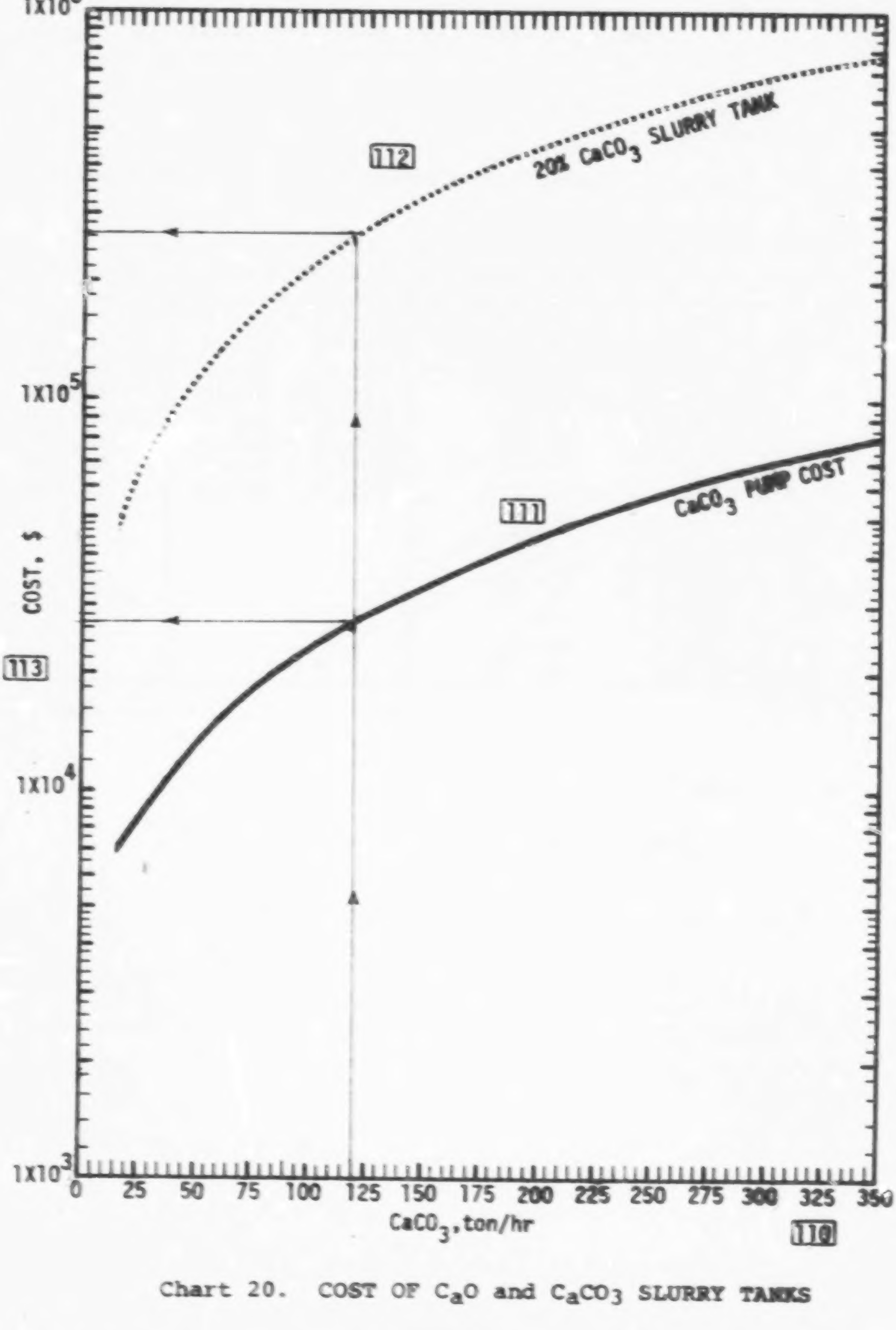


Chart 20. COST OF C_aO and C_aCO_3 SLURRY TANKS

POND ACREAGE AND POND EXCAVATING/DIKING COSTS

To determine the cost of pond acreage, excavating/diking costs, Chart 21:

Enter from page B-10, Chart 3 item $\boxed{16}$ (ton/hr dry sludge) Chart 21, item $\boxed{115}$ then move vertically upward to the respective weighted capacity factor, item $\boxed{116}$

From item $\boxed{116}$ move horizontally left to item $\boxed{117}$ (acre ft/yr) and reference line $\boxed{118}$ and read: ______________ $\boxed{117}$

Select plant remaining life on item $\boxed{119}$

Connect items $\boxed{118}$ and $\boxed{119}$ and extend to item $\boxed{120}$ (pond acre-ft)

and read: ______________ $\boxed{120}$

From item $\boxed{120}$ move horizontally left to item $\boxed{121}$ (pond reference scale)

From item $\boxed{121}$ move vertically down to item $\boxed{122}$ (pond cost)

and read: $ ______________ $\boxed{122}$ dry sludge

If wet sludge, no waste return 1.67 x $\boxed{120}$ = ______ pond acre-ft $\boxed{123}$ wet sludge

Enter item $\boxed{123}$ on Chart 21, item $\boxed{120}$ and move horizontally left to item $\boxed{121}$

From item $\boxed{121}$ move vertically down to item $\boxed{122}$ (pond cost) and read:

$ ____________ $\boxed{124}$ wet sludge pond cost

Select proper item $\boxed{122}$ or $\boxed{124}$ and record as pond cost, $ ________ $\boxed{125}$

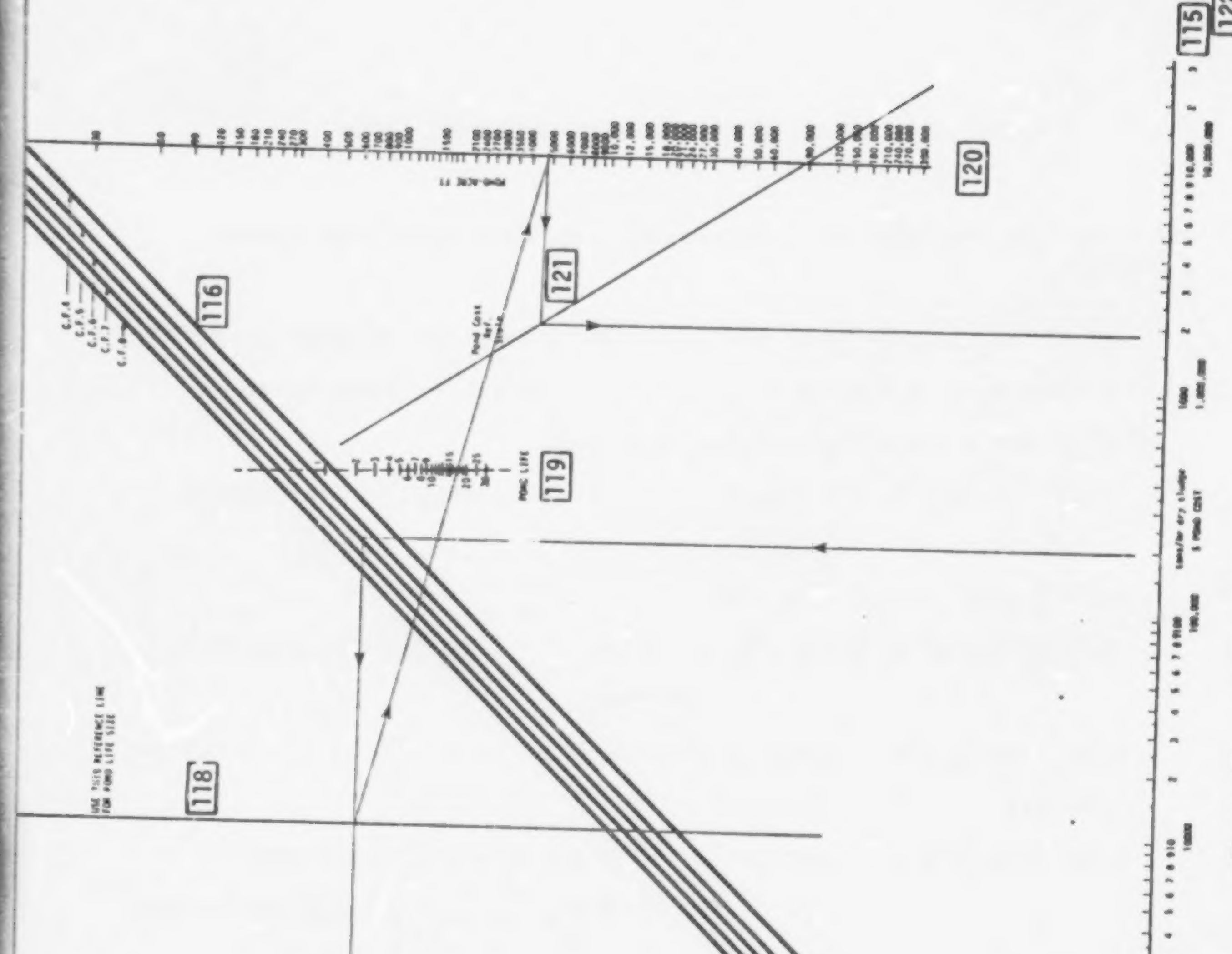


Chart 21. POND COST

MOBILE EQUIPMENT

From Richardson's - capacity to move 60 ton/hr limestone from storage pile

Cost $44,000

Requirements: based on ton/hr required
- Same unit as above for fixation process capable of handling 1,300,000 gal./wk of fixed sludge

EQUIPMENT COST - LIMESTONE

	Equipment	Item	Cost, $
1.	Absorber	$\boxed{27}$ A	
2.	Venturi and absorber	$\boxed{27}$ V+A	
3.	Venturi	$\boxed{27}$	
4.	Absorber and/or venturi holding tanks agitators	$\boxed{35}$ T	
5.	Absorber and/or venturi holding tanks	$\boxed{39}$ T	
6.	Circulation holding tanks pumps	$\boxed{49}$ T	
7.	I.D. fans	$\boxed{52}$	
8.	Heat exchangers	$\boxed{55}$	
9.	Soot blowers	$\boxed{59}$	
10.	Ducting	$\boxed{70}$	
11.	Conveyors	$\boxed{77}$	
12.	Bypass valving	$\Sigma\ \boxed{84}$	
13.	Ball mills	$\boxed{90}$ T	
14.	Ball mill tank and pumps	$\boxed{97}$	
15.	Dry storage	$\boxed{100}$ S	
16.	Fixation silo	$\boxed{101}$	
17.	Solids disposal - clarifiers, vacuum filtration, pumps	$\boxed{109}$	
18.	Limestone slurry tanks and pumps	$\boxed{114}$	

EQUIPMENT COST

19. Mobile equipment Page B-50 __________

20. New roadways or RR siding at $50/ft, estimated length Page B-50 __________

____

Total equipment costs: __________

Year of FGD system operation ______

Select cost factor index multiplier from Page B-52

for the year above ______

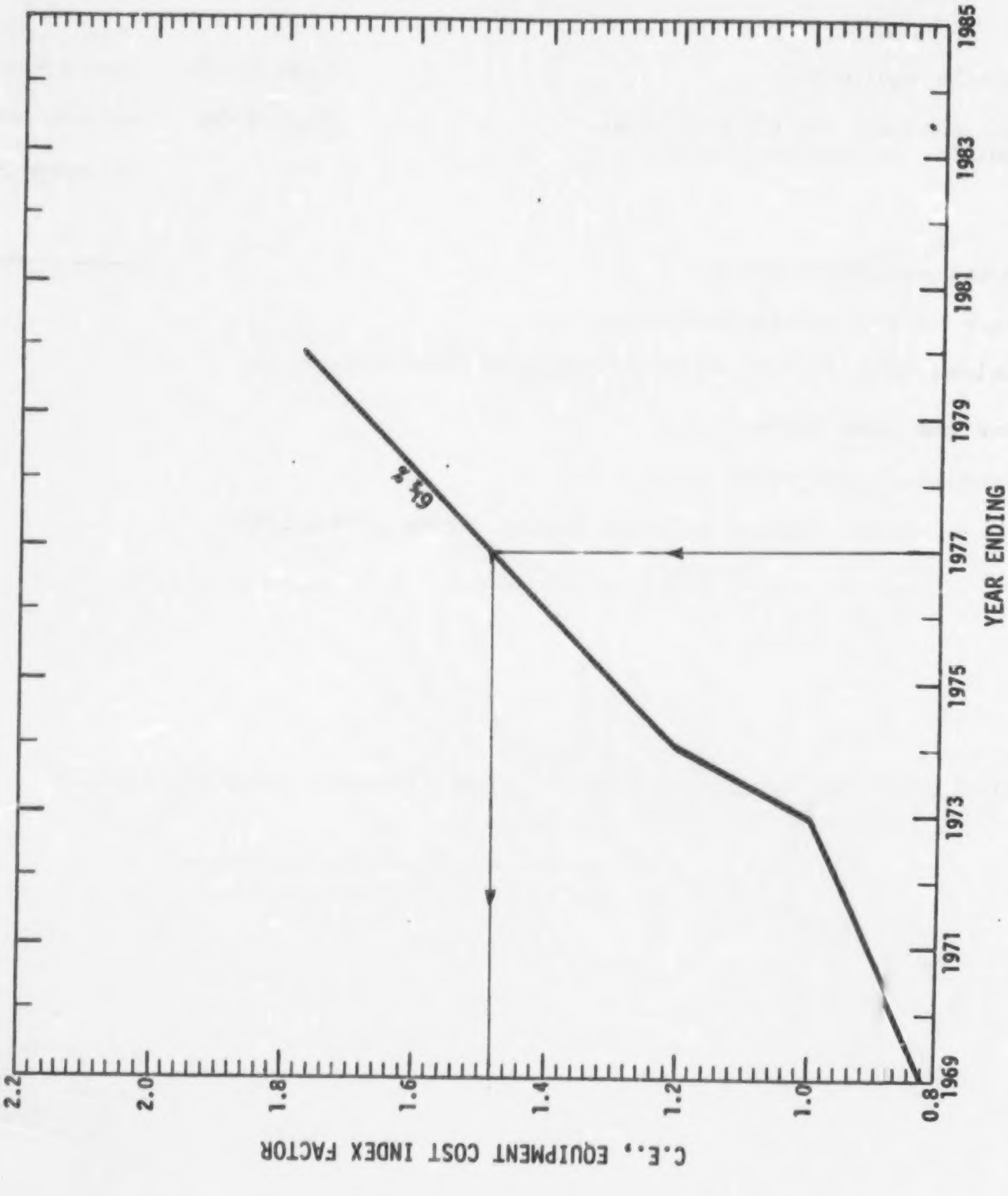
Predicted equipment costs:

(total costs) x (cost factor index multiplier)

(__________) x (______________) = $______________

Predicted pond cost = pond cost x cost factory index multiplier from item $\boxed{122}$ or $\boxed{125}$

= __________ x ______________ =


C.E., EQUIPMENT COST INDEX FACTOR
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
YEAR ENDING
1969
1971
1973
1975
1977
1979
1981
1983
1985
6.5%

CAPITAL INVESTMENT COSTS--LIMESTONE

Direct costs:

	Absorber or venturi	Absorber & venturi	Cost,$
Select system required			
"A" Material	$1.646\lambda^{a}$	1.639λ	
"B" Labor	0.814λ	0.822λ	
"C"	Materials and labor		
Retrofit	Absorber	Absorber-venturi	
Easy	0	0	———
Moderate	0.047λ	0.039λ	
Difficult	0.093λ	0.077λ	

[a] λ = Equipment cost, predicted from page B-53

"A" + "B" + "C" = $____________

"D" Raw materials: Chart 15, item $\boxed{71}$ page_____

ton/hr $CaCO_3$ x 30 day storage x \$/ton[b] =

__________ x 720 x _______ = $____________

[b] If unknown use $6.32/ton

"E" Predicted pond costs, page B-53 = $__________

"F" Direct costs ("A" + "B" + "C" + "E") above = $__________

"G" Direct costs ("A" to "E" inclusive) = $__________

"H" Direct costs ("A" + "B" + "C") above = $__________

Indirect costs:

"J" Interest (at 8%), contractor fees and expenses, engineering, freight, off-site, taxes, start-up, spares -

(0.33 "G") + (0.1 "H") + (0.065 "F")

(0.33 x______) + (0.1 x ______) + (0.065 x ______) = $__________

"K" Contingency:
0.2 ("J" + "F") = 0.2 (______+______) = $__________

"L" Total costs for capital investment

"G" + "J" + "K" = ______+______+______ = $__________

Cost/Kilowatt:

$$\frac{L}{\text{MW's} \times 1{,}000} = \frac{\_\_\_\_\_\_}{\times 1{,}000} = $$

$________/KW

TOTAL ANNUAL OPERATING COSTS--LIMESTONE

Utilities -

Water: Limestone scrubbing

66 gal./MW for 3.0% S coal $\boxed{126}$

±Δ6 gal./MW for each ± 1.0% S in coal $\boxed{127}$

55 gal./MW for 2.0% S oil $\boxed{128}$

±Δ5 gal./MW for each ± 1.0% S in oil $\boxed{129}$

Limestone:

(gal./MW ± gal./MW corr. for % S) x hr/yr x weighted capacity factor x water costs/1,000 gal. = Yearly cost water/MW $\boxed{130}$

($\boxed{126}$ or $\boxed{128}$ ± $\boxed{127}$ or $\boxed{129}$) x C.F.

(____________ ± ____________) x ________ x 8760 x $\frac{\$0.02}{1{,}000 \text{ gal.}}$ = $/MW

$______________ $\boxed{130}$

$\begin{pmatrix}\text{Coal}\\ \text{or oil}\end{pmatrix}$; $\begin{pmatrix}\text{Base; \% S}\\ \text{\% S corr.}\end{pmatrix}$; $\boxed{130}$ x MW = $\boxed{131}$

(__________); (______; ______); __________ x ____________ = $__________/yr $\boxed{131}$

Reheat:

From page B-31, Chart 13, item $\boxed{65}$ determine $/reheat (see calculation sheet)

$________________/yr $\boxed{65}$

For ΔT ______°F

TOTAL ANNUAL OPERATING COSTS--LIMESTONE

Operating labor cost:

MW's	Men/Shift
100- 699	3.33
700-1200	3.67
1201-2500	5.00
2501-	6.00

Men/shift x hr/yr x $/hr = $\boxed{132}$

__________ x 8760 x 6.50 = $\boxed{132}$

__________ x 56,940 = $__________/yr $\boxed{132}$

Corrected cost: $\boxed{132} \times \left(\frac{\$/\text{hr (manpower)}}{6.50}\right) = \$$ ________/yr $\boxed{132}_{C}$

Supervision:

0.15 x 56,940 x men/shift = $\boxed{133}$

8541 x __________ = $ __________/yr $\boxed{133}$

Corrected cost: $\boxed{132}_{C} \times 0.15 = \$$ __________/yr $\boxed{133}_{C}$

Maintenance:

Capital costs, total

0.046 x ____________________ = $ __________/yr $\boxed{134}$

Overhead:

Capital cost, total + Men/shift

(0.023 x __________) + (13,100 x _____) =

(____________________)+(____________________)=

= $ ______________/yr $\boxed{135}$

TOTAL ANNUAL OPERATING COSTS--LIMESTONE

Fixed costs -

A. $\frac{100}{\text{Plant life, yrs*}}$ = ____________ %/yr depreciation, straight-line

B Capital = %/yr________ %

C. Taxes, insurance, interim replacement - 4.65%

Total fixed costs = $\frac{A + B + C}{100}$ = 0.______/yr fixed costs

(Yr fixed costs) x (total capital cost) =

(0.______________) x(____________________)= $____________/yr $\boxed{136}$

Sludge disposal:

Pumping to another site, off-plant

MW KW/MW $/KWH**or*** hr/yr x weighed CF

0.0016 x ________ x 1000 x __________ x 8760 x ________ =

MW $/KWH** or *** weighed CF

14,016 x_______x_______________x__________= $_____________/yr $\boxed{137}$

Truck disposal costs/14 miles:

$\frac{\text{ton dry sludge/hr}}{\text{8.47 tons dry sludge/truck hr}}$ x $17.20 x 1.1 x 8760 x CF =

(57.25 min/trip) ($17.20/truck hr/driver)

From Chart 3, item $\boxed{16}$, tons dry sludge/hr________________$\boxed{16}$

$\boxed{16}$ weighed CF

____________x 19,570 x ______________= $___________/yr $\boxed{138}$

---

* Plant life, years: either remaining boiler life in years from start of FGD system or 15 year life for FGD system, use lowest number of years for life.

** or *** see next page

TOTAL ANNUAL OPERATING COST--LIMESTONE

Raw Materials -

Limestone:

Page B-35, Chart 15, item $\boxed{71}$ ________ ton/hr $CaCO_3$ x hr/yr x weighed CF x \$/ton[a] = cost/yr. $\boxed{139}$

Chart 15, item $\boxed{71}$ x hr/yr x CF x \$/ton[a] = cost/yr $\boxed{139}$

________________ x 8760 x __________ = \$ ______________ $\boxed{139}$

Fixation

Page B-10, Chart 3,
item $\boxed{16}$

______ lb/hr dry sludge x $\frac{\text{hr/yr}}{\text{lb/ton}}$ x weighed CF x \$/ton[b] = cost/yr $\boxed{140}$

__________________ x 4.38 x ________ x _______ = \$ _________ $\boxed{140}$

Utilities:

Electrical, use appropriate
Limestone--burning coal =

MW x x \$/KWH* x Weighed CF x hr/yr = cost/yr
0.025 x _____ x 1,000 x _______ x ___________ x 8760 = \$ _______ $\boxed{141}$

MW \$/KWH CF
2.19 x 10^5 x ______ x ______ x ______ = \$ ___________________ /yr =
(on coal/abs. + vent.)
\$ ____________ $\boxed{141}$ A+V

1.971 x 10^5 x _____ x ______ x ______ = \$ ____________________ /yr =
(on coal/abs. or vent.)
\$ ____________ $\boxed{141}$ A

Limestone--burning fuel oil =

MW \$/KWH** CF
1.374 x _______ x _______ x ________ = \$ _____________ = \$ ___________ $\boxed{141}$ O
(on oil/abs.)

---

[a] If unknown use \$6.32/ton

[b] If unknown use \$4/ton of dry sludge

[**] If unknown use 0.00675/KWH based on coal at \$10/ton and 12,000 BTU/lb

[***] If unknown use 0.0185/KWH based on oil of \$8.40/bbl and 149,000 BTU/gal

TOTAL ANNUAL OPEPATING COSTS - LIMESTONE

Summary sheet

	Item	Cost, $
1. Water	$\boxed{131}$	______
2. Reheat	$\boxed{65}$	______
3. Operating labor	$\boxed{132}_c$	______
4. Supervision	$\boxed{133}_c$	______
5. Maintenance	$\boxed{134}$	______
6. Overhead	$\boxed{135}$	______
7. Fixed costs	$\boxed{136}$	______
8. Sludge disposal, pumping	$\boxed{137}$	______
9. Sludge disposal, trucking	$\boxed{138}$	______
10. Limestone	$\boxed{139}$	______
11. Fixation	$\boxed{140}$	______
12. Electrical	$\boxed{141}_{A+V}$	______
	$\boxed{141}_O$	______
	$\boxed{141}_A$	______
Total annual operating costs		______

Cost per kilowatt-hour:

$$\frac{\text{(total annual operating cost)}}{\text{hr/yr x (plant rating in MW's) x 1,000 x (weighed capacity factor)}} =$$

$$\frac{(\qquad\qquad\qquad)}{8760 \text{ x } (\qquad) \text{ x } 1{,}000 \text{ x } (\qquad)} = \$\_\_\_\_\_\_\_\_/\text{KWH}$$

APPENDIX C

DOUBLE ALKALI SCRUBBING

NOTE: For purposes of clarity and continuity, Tables and Charts have been numbered sequentially in this report with no differentiation between Tables and Charts.

DOUBLE-ALKALI

INFORMATION REQUIRED

Boiler No.						
Type of unit furnace						
MW at maximum continuous						
Age of unit, years						
Life, years remaining						
Capacity factor, yr.						
Maximum continuous fuel, ton/hr or gal./min						
Maximum continuous, MM BTU/hr						
acfm at ___°F						
Fly ash/total ash, %						
Efficiency of existing particulate control, %						

Cost of electricity/kW (Plant) =$ ______. Cost of water/M gal. (Plant)

Coal, cost/ton $ ________

% sulfur by weight ________

% ash by weight ________

HHV, BTU/lb ________

Oil, cost/bbl $________

% sulfur by weight ________

BTU/gal ________

Specific gravity ________

SO_2 permissible ________ lb SO_2/MM BTU

Fly ash permissible ________ lb fly ash/MM BTU

State or
Federal regulations

INFORMATION REQUIRED (continued)

Estimated land cost per acre (current) $______________

Possible interference determining the location of flue gas desulferization (FGD) system:

Congestion between stack and plant ☐ Yes ☐ No

Congestion between stack and/or plant with property line, coal pile, etc., ☐ Yes ☐ No

Identify problem areas and location: ______________________________

____

Terrain ____

____

Conduits ____

____

Possible obstructions ____

____

Source of Na_2CO_3 available _______________________________________

and % purity ________

Source of CaO available ____

% purity ________

SO_2 EMISSION DETERMINATION

To determine the SO_2 emissions (lb/MM BTU) in the flue gas, Chart 1:

Enter % sulfur by weight of fuel (oil or coal) on $\boxed{1}$

Enter heating value of fuel (BTU/lb) on $\boxed{2}$

Connect $\boxed{1}$ and $\boxed{2}$ and extend to $\boxed{3}$ and read and record:

SO_2 emissions (lb/MM BTU) in flue gas ____________ $\boxed{3}$

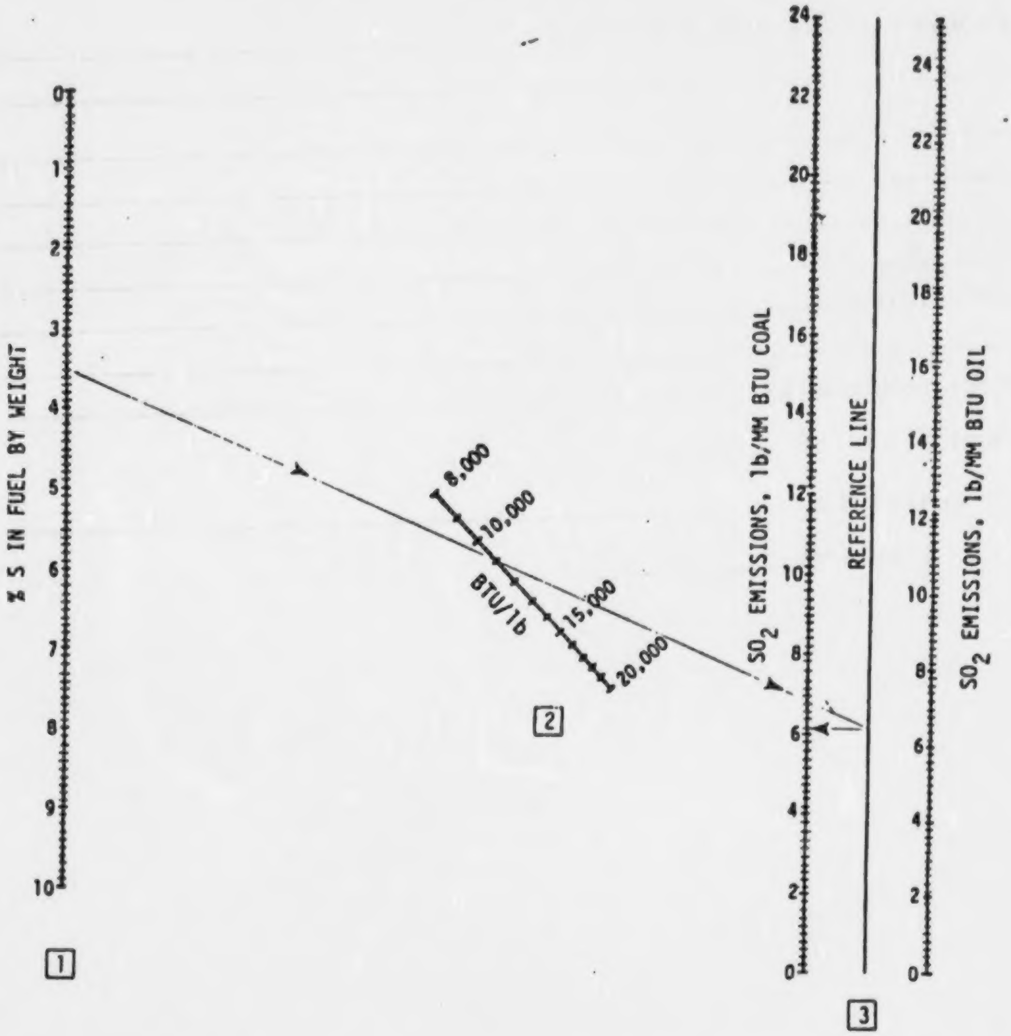


Chart 1. SO_2 EMISSION DETERMINATION

Assumptions:

(1) 95% of sulfur in coal converted to SO_2

(2) 100% of sulfur in oil converted to SO_2

SO_2 REMOVAL REQUIREMENTS

To calculate SO_2 emissions (lb/MM BTU) to be removed:

Enter from page C-4, Chart 1, item $\boxed{3}$ the lb/MM BTU ________ $\boxed{3}$

Enter from the data sheet, allowable SO_2 emissions (lb/MM BTU) from the State or Federal regulations ________ $\boxed{4}$

Subtract $\boxed{4}$ from $\boxed{3}$ to calculate SO_2 emissions (lb/MM BTU) to be removed ________ $\boxed{5}$

LIME REQUIREMENTS

To determine the lime requirements (lb/hr) Chart 2:

Enter the SO_2 emission (lb/MM BTU) to be removed on item $\boxed{6}$ from page C-5, item $\boxed{5}$; record________________ $\boxed{6}$

Enter stoichiometric* requirements for lime on item $\boxed{7}$

Connect $\boxed{6}$ and $\boxed{7}$ and extend to $\boxed{8}$ and read and record:

Lime requirements (lb/MM BTU) ________________ $\boxed{8}$

Record from the data sheets the heat input (MM BTU/hr) _____ $\boxed{8}_A$

Multiply $\boxed{8} \times \boxed{8}_A$ and record:

Lime requirements (lb/hr) ____________________ $\boxed{8}_B$

Multiply $\boxed{6}$ by $\boxed{8}_A$ and record: lb SO_2/hr removed

______________ $\boxed{8}_C$

---

*If unknown, use 1.1.

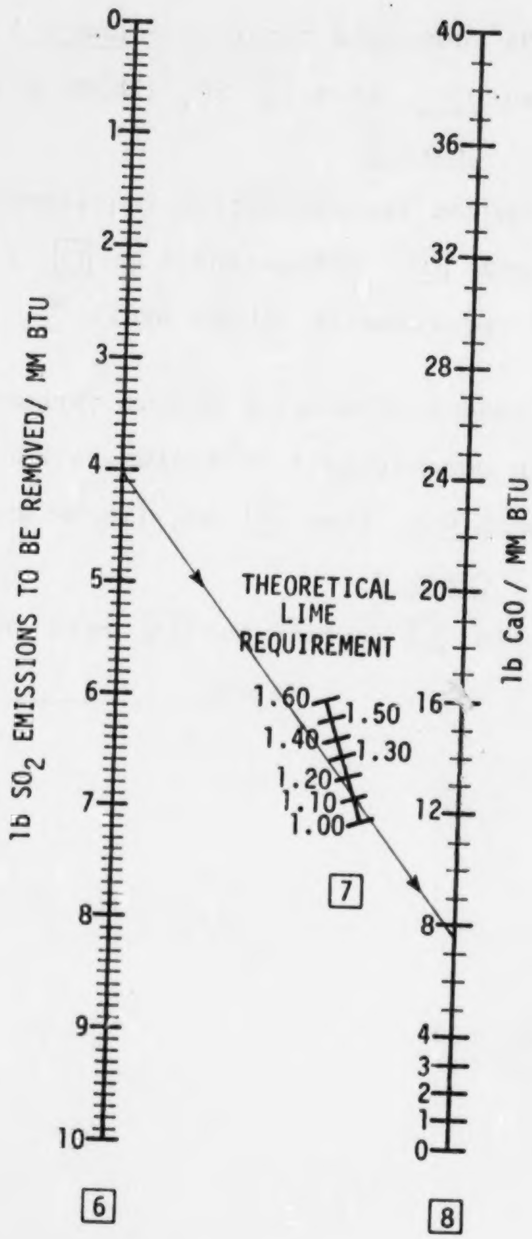


Chart 2. LIMESTONE REQUIREMENTS

Na^+ COMPOUND IN CIRCULATION

MAKE-UP SODIUM CARBONATE REQUIREMENTS

To determine the Na^+ compound required - Chart 3

Enter from page C-5, item $\boxed{5}$ SO_2 (lb/MM BTU) to be removed on item $\boxed{9}$, Chart 3

Enter Na^+ compound stoichiometric requirements* on $\boxed{10}$

Connect $\boxed{9}$ and $\boxed{10}$ and extend to, $\boxed{11}$, read and record Na^+ compound requirements (lb/MM BTU): __________ $\boxed{11}$

To determine the amount of make-up sodium carbonate required - Chart 3

Enter make-up percentage** of sodium carbonate on $\boxed{12}$

Enter from page C-5, item $\boxed{5}$ SO_2 (lb/MM BTU) to be removed on item $\boxed{9}$, Chart 3

Connect $\boxed{9}$ and $\boxed{12}$ extend to $\boxed{13}$ read and record

Na_2CO_3 __________________ lb/MM BTU $\boxed{13}$

---

* If unknown, use 1.05.
** If unknown, use 5%.

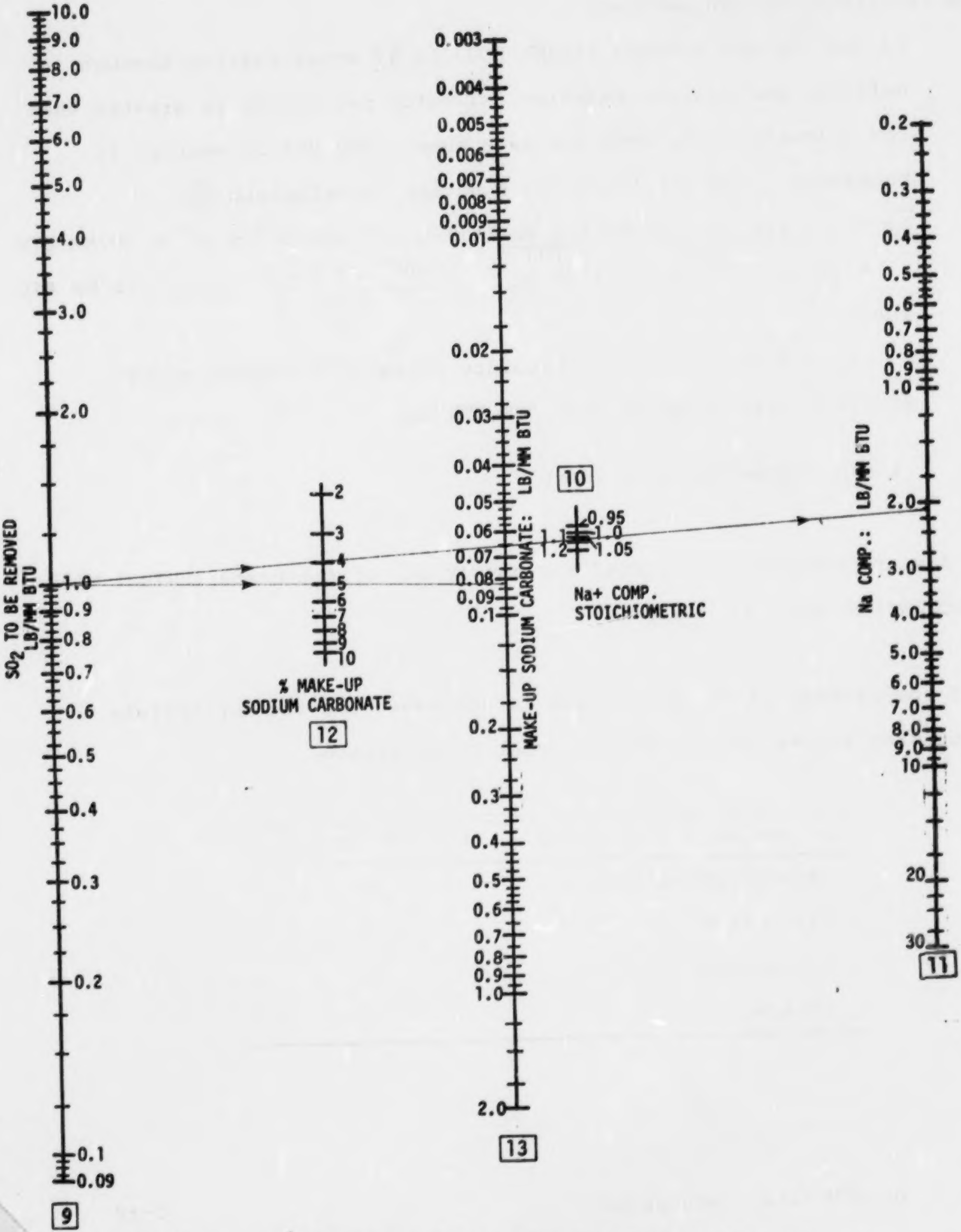


Chart 3. Na^+ COMPOUND AND SODIUM CARBONATE REQUIREMENTS

FLY ASH EMISSION RATE CALCULATIONS FOR VENTURI DETERMINATION

To calculate fly ash emitted:

If the fly ash emitted (lb/MM BTU) in $\boxed{14}$ after passing through an existing particulate emission collector per boiler is greater than the allowable rate from the data sheet, the use of venturi is necessary. Use the following equation to calculate $\boxed{14}$

$$\boxed{14} = \left[\left(\frac{\%\ \text{ash in coal}}{100}\right)\left(\frac{\%\ \text{fly ash}^*}{100}\right)\left(1-\frac{\eta_c}{100}\right) \div \text{BTU/lb}\right] \times 10^6 = \text{lb/MM BTU}$$

$$= \left[(0.\underline{\qquad})(0.\underline{\qquad})\ (1-0.\underline{\quad}) \div \underline{\qquad\quad}\right] \times 10^6 = \underline{\qquad}\ \text{lb/MM BTU}$$

where

η_c = Efficiency of particulate emission collector system

BTU/lb = Heat value of fuel (MM BTU/lb)

% ash = from the data sheet

If fly ash removal is required for any or all of the units VENTURI COST CALCULATIONS will be used.

*If the percent of fly ash to ash is not known use the appropriate tabulated values for the boiler under consideration.

Type boiler - coal-fired	fly ash to ash, %
General pulverized	80
Dry bottom	85
Wet bottom	65
Cyclone	10

SLUDGE GENERATED

To determine the dry sludge (lb/hr) generated, item $\boxed{16}$, Chart 4:

From page C-10, item $\boxed{14}$ enter calculation of fly ash (lb/MM BTU)

________ $\boxed{14}$

From page C-5, item $\boxed{5}$ enter lb SO_2/MM BTU ________ $\boxed{5}$

From page C-7, Chart 2 item $\boxed{8}$ enter lb CaO/MM BTU $\boxed{8}$

From page C-9, Chart 3 item $\boxed{13}$ enter lb Na_2CO_3/MM BTU $\boxed{9}$

$\boxed{14} + \boxed{5} + \boxed{8} + \boxed{9} = \boxed{15}$ total dry sludge (lb/MM BTU)

________ $\boxed{15}$

From data sheet, heat input maximum continuous rating, record here as (MM BTU/hr) ________ $\boxed{16}$

Dry Sludge = $\boxed{15}$ x $\boxed{16}$ = $\boxed{17}$ lb/hr

= ________ x ________ = ________ lb/hr $\boxed{17}$

$\boxed{17} \div 2000 = \boxed{17}_A$ ton/hr ton/hr ______ $\boxed{17}_A$

Wet sludge - Enter $\boxed{17}$ on $\boxed{18}$, Chart 4 and divide by percent weight dry sludge on $\boxed{18}$ = Sludge slurry, lb/hr

$\boxed{18}$ $\boxed{19}$ $\boxed{20}$

= ________ ÷ 0.6* = ________ lb/hr $\boxed{20}$*

*If other than 60 percent by weight is used, use that value on $\boxed{19}$.

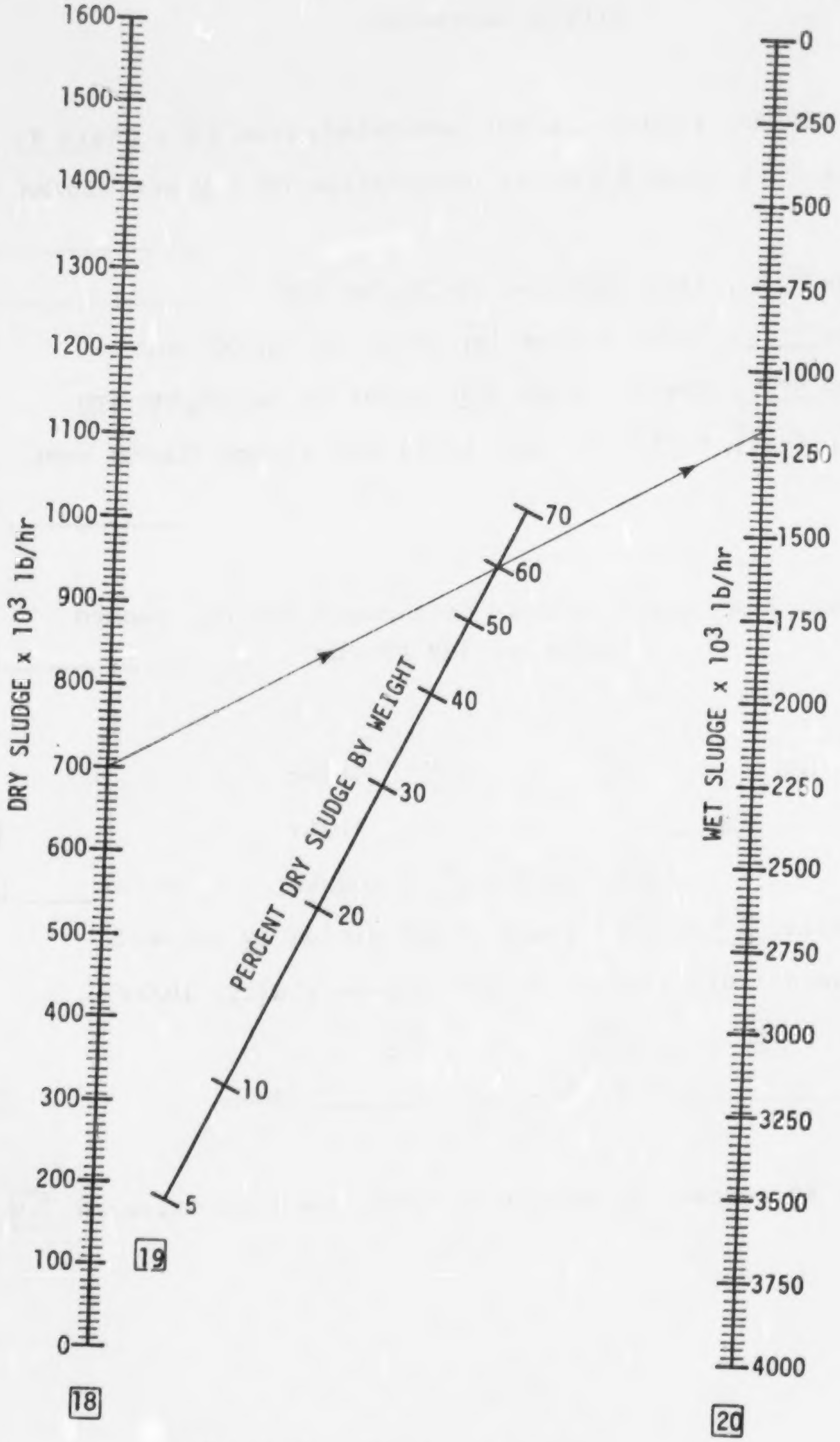


Chart 4. SLUDGE GENERATED

VENTURI AND ABSORBER COSTS

To determine the costs of venturi and absorber (including demister) using Na^+ compound, Chart 5

First, determine number of scrubber trains -

Enter acfm at °F of flue gas from the data sheet on $\boxed{21}$, either per boiler or combined plant total if °F is the same for all boilers.

Enter temperature of flue gas (°F) on $\boxed{22}$

Connect $\boxed{21}$ and $\boxed{22}$ and extend to $\boxed{23}$ and read flue gas acfm at 125°C (saturated) and enter________acfm at 125°F and sat. $\boxed{23}$

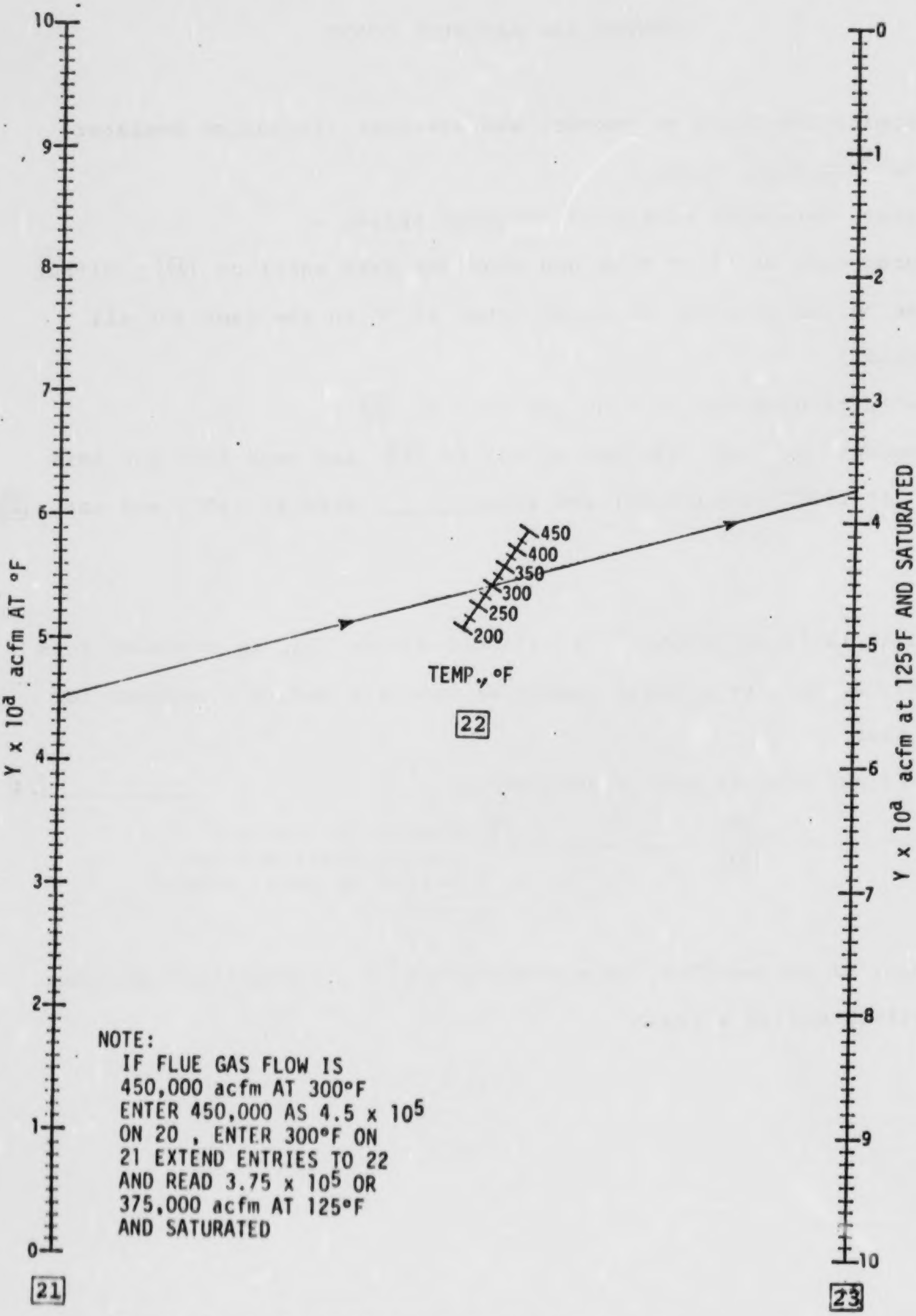
If acfm at 125°F is greater than 375,000 divide $\boxed{23}$ by a number less than 375,000 to give a whole number of venturis and/or absorbers for each boiler.

acfm per venturi and/or absorber ____________ $\boxed{24}$

$$\frac{\_\_\_\_\_\_\_\_\_\_\_\_ \boxed{23}}{\boxed{24}} = \_\_\_\_\_\_\_\_\_\_\_\_ \boxed{25}$$

number of venturis
and/or absorbers per
boiler or power plant.

A venturi, or an absorber, or a combination of a venturi and absorber is sometimes called a train.



NOTE:
IF FLUE GAS FLOW IS
450,000 acfm AT 300°F
ENTER 450,000 AS 4.5 x 10^5
ON 20 , ENTER 300°F ON
21 EXTEND ENTRIES TO 22
AND READ 3.75 x 10^5 OR
375,000 acfm AT 125°F
AND SATURATED

Chart 5. acfm CORRECTED TO 125 °F AND SATURATED

VENTURI AND ABSORBER COSTS

Then determine absorber costs (no venturi required) Chart 6:

Enter item $\boxed{23}$ from page C-14, Chart 5 on Chart 6 on $\boxed{26}$

Enter for the absorber the cost factor of 1.65 on $\boxed{27}$

Connect $\boxed{26}$ and $\boxed{27}$ and extend to $\boxed{28}$ and read absorber cost

\$ ______________ $\boxed{28}$ A

Or determine venturi and absorber costs (if a venturi is required) Chart 6

Enter item $\boxed{23}$ from page C-14, Chart 5 on Chart 6 on $\boxed{26}$

Enter for the train the cost factor of 2.55 on $\boxed{27}$

Connect $\boxed{26}$ and $\boxed{27}$ and extend to $\boxed{28}$ and read venturi and absorber costs \$ ______________ $\boxed{28}$ V + A

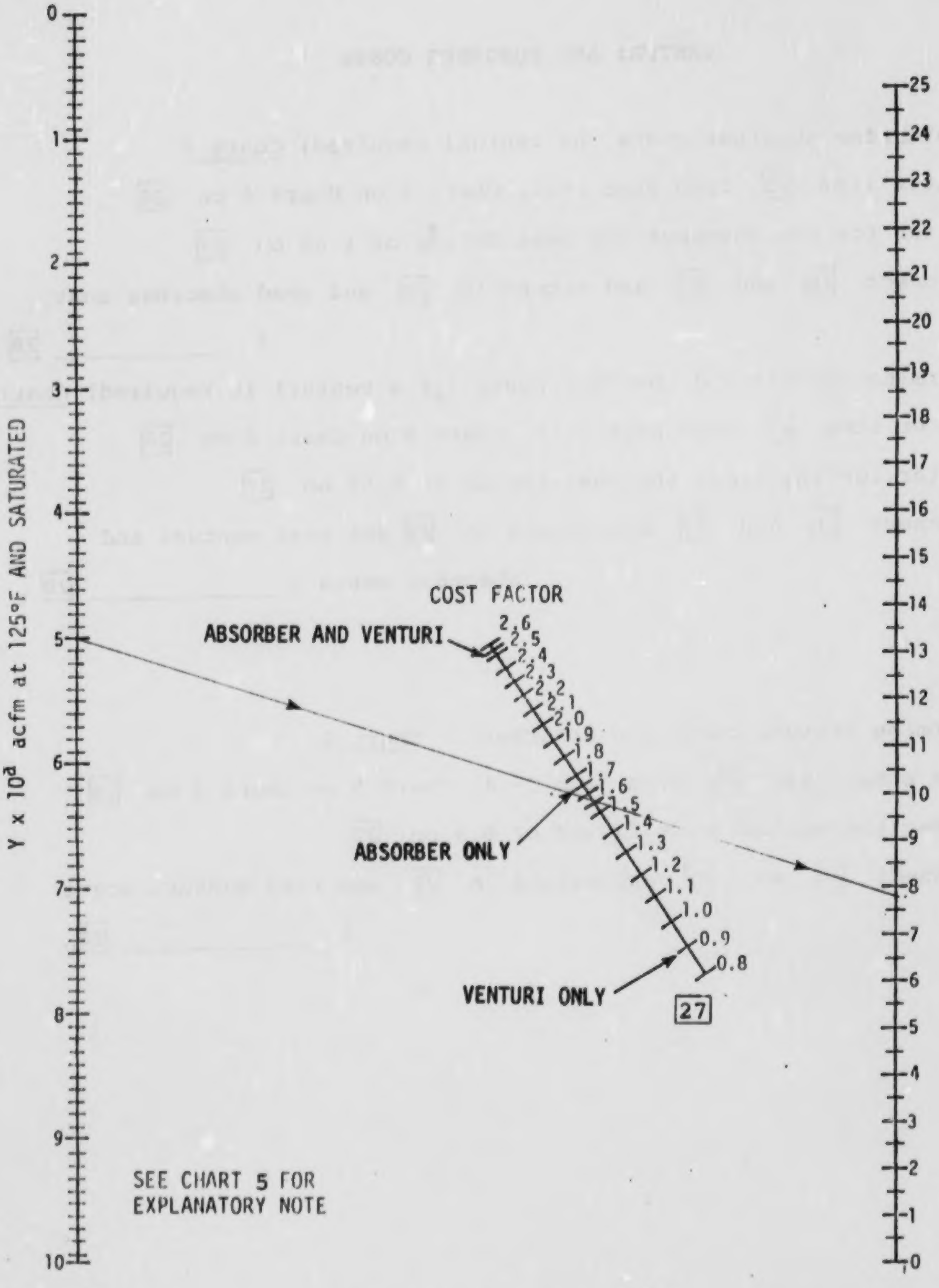
Or determine venturi costs (no absorber): Chart 6

Now enter item $\boxed{23}$ from page C-14, Chart 5 on chart 6 on $\boxed{26}$

Enter the venturi cost factor of 0.9 on $\boxed{27}$

Connect $\boxed{26}$ and $\boxed{27}$ and extend to $\boxed{28}$ and read venturi costs

\$ ______________ $\boxed{28}$ V



SEE CHART 5 FOR EXPLANATORY NOTE

Chart 6. SCRUBBER COSTS

HOLDING TANK CAPACITY

To determine the holding tank capacity for absorber and/or venturi

Chart 7:

Enter flue gas acfm from page C-16, Chart 5, item $\boxed{24}$ on Chart 7, item $\boxed{29}$

Enter L/G* (liquid flow rate, gpm/1000 acfm at 125°F) on $\boxed{30}$

Connect $\boxed{29}$ and $\boxed{30}$ and extend to $\boxed{31}$, read and record:

Liquid flow rate (gal./min) ___________ $\boxed{31}_A$ for absorber

Liquid flow rate (gal./min) ___________ $\boxed{31}_V$ for venturi

Enter retention time** on $\boxed{32}$

Connect $\boxed{31}$ and $\boxed{32}$ and extend to $\boxed{33}$, read and record:

Tank capacity (gal.) per absorber _______ $\boxed{33}_A$

(gal.) per venturi ________ $\boxed{33}_V$

---

* If unknown, use 20

** If unknown, use 6 min.

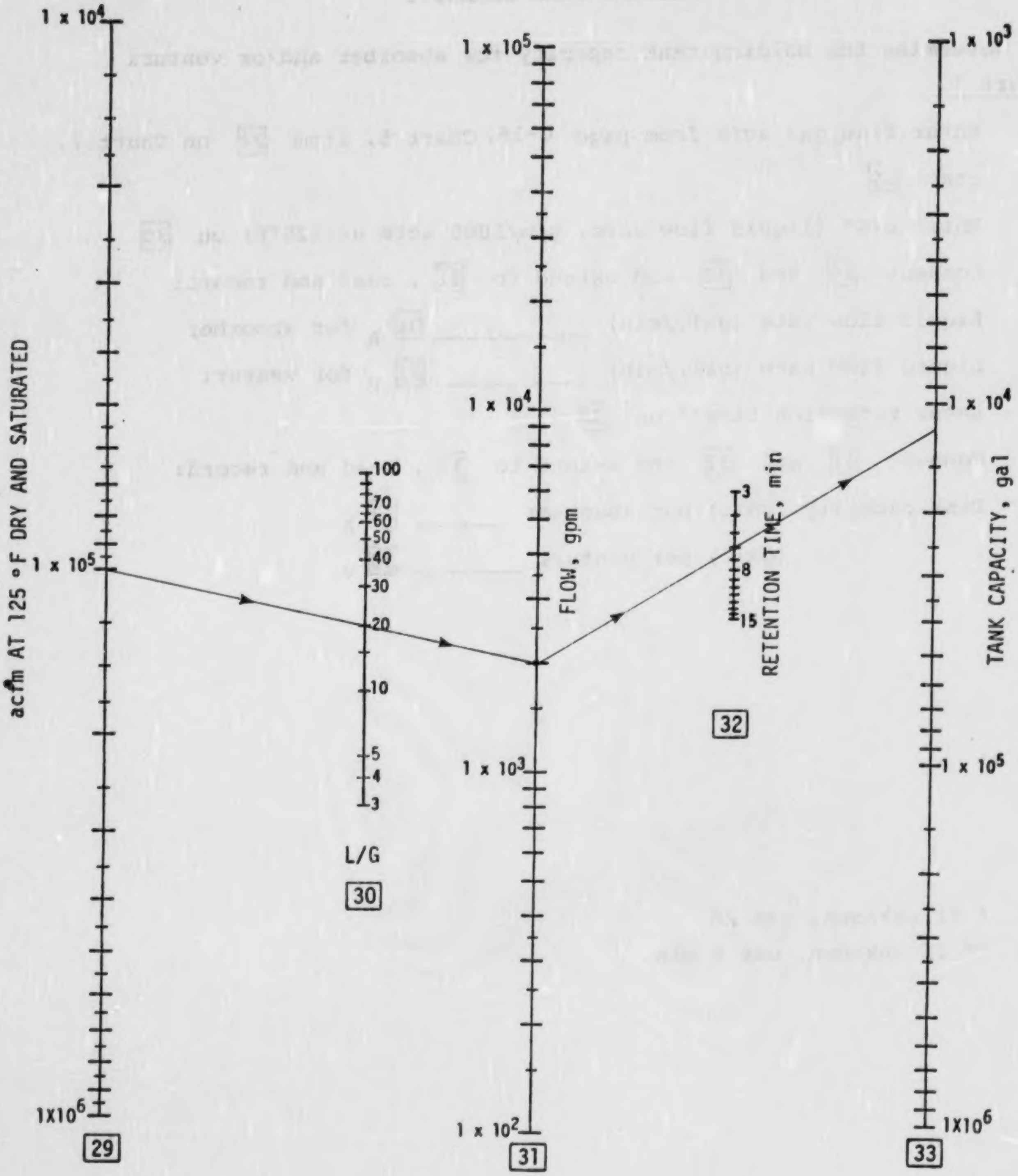


Chart 7. FLOW RATE AND TANK CAPACITY

HOLDING TANK AGITATOR COSTS

To determine the cost of agitators per tank, Table 8:

Compare tank capacity (gallons) from page C-18, Chart 7, item $\boxed{33}_A$ and/or $\boxed{33}_V$ on Table 8; under tank capacity in gallons column and record:

Cost of agitators per tank - absorber \$ ____________ $\boxed{34}_A$

venturi \$ ____________ $\boxed{34}_V$

Total cost of venturi and/or absrober:

$(\boxed{34}_A + \boxed{34}_V) \times$ No. of venturi of absorbers from page C-13, item $\boxed{25}$ = $\boxed{35}$

(________ + ________) ________ = \$__________ $\boxed{35}$

Table 8. AGITATOR COST

Tank capacity, gal.	Agitators	
	No.	$\boxed{34}_A$ or $\boxed{34}_V$, cost, \$
0 to 34,000	1	2,000
34,000 to 67,000	2	4,000
67,000 to 101,000	3	6,000
101,000 to 135,000	4	8,000
135,000 to 162,000	5	10,000
162,000 to 188,000	6	12,000
188,000 to 220,000	7	14,000
220,000 to 251,000	8	16,000
251,000 to 283,000	9	18,000

TABULATE THE COST OF TANK, PUMP AND AGITATOR AS BELOW, IF VENTURI IS REQUIRED, PREPARE SEPARATE TABLES FOR VENTURI AND ABSORBER. PLANT TOTALS $\boxed{39}_{T}$, $\boxed{45}_{T}$, AND $\boxed{35}_{T}$ SHOULD INCLUDE ABSORBER AND VENTURI EQUIPMENT.

Boiler No.	Flue gas rate, acfm	Flue gas temp, F.	Flue gas a 125° F, acfm	No. of trains	Flue gas rate @125°F per train	Tank cost per train, $	Tank cost per boiler, $	Pump cost per train, $	Pump cost per boiler, $	Agitator cost per train, $	Agitator cost per train, $
Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ	Ⓕ	Ⓖ	Ⓖ x Ⓔ	Ⓗ	Ⓗ x Ⓔ	Ⓙ	Ⓙ x Ⓔ
Total/plant											
							$\boxed{39}_{T}$		$\boxed{45}_{T}$		$\boxed{35}_{T}$

HOLDING TANK COSTS

To determine the tank cost the values in the chart are based on using \$12.50/ft^2 for a field-fabricated, rubber-lined tank, Chart 9:

Enter tank capacity (gallons) on $\boxed{36}$ from page C-18, Chart 7, items $\boxed{33}_A$ and $\boxed{33}_V$, move vertically to $\boxed{37}$

From $\boxed{37}$ move horizontally to $\boxed{38}$, read and record:

Tank cost per absorber \$________________ $\boxed{38}_A$

per venturi \$________________ $\boxed{38}_V$

Total Cost:

($\boxed{38}_A$	+	$\boxed{38}_V$	) x	No. of absorbers from page C-13, item $\boxed{25}$	=	cost of holding tanks $\boxed{39}$
(________	+	__________	) x	__________________	=	\$__________________ $\boxed{39}$

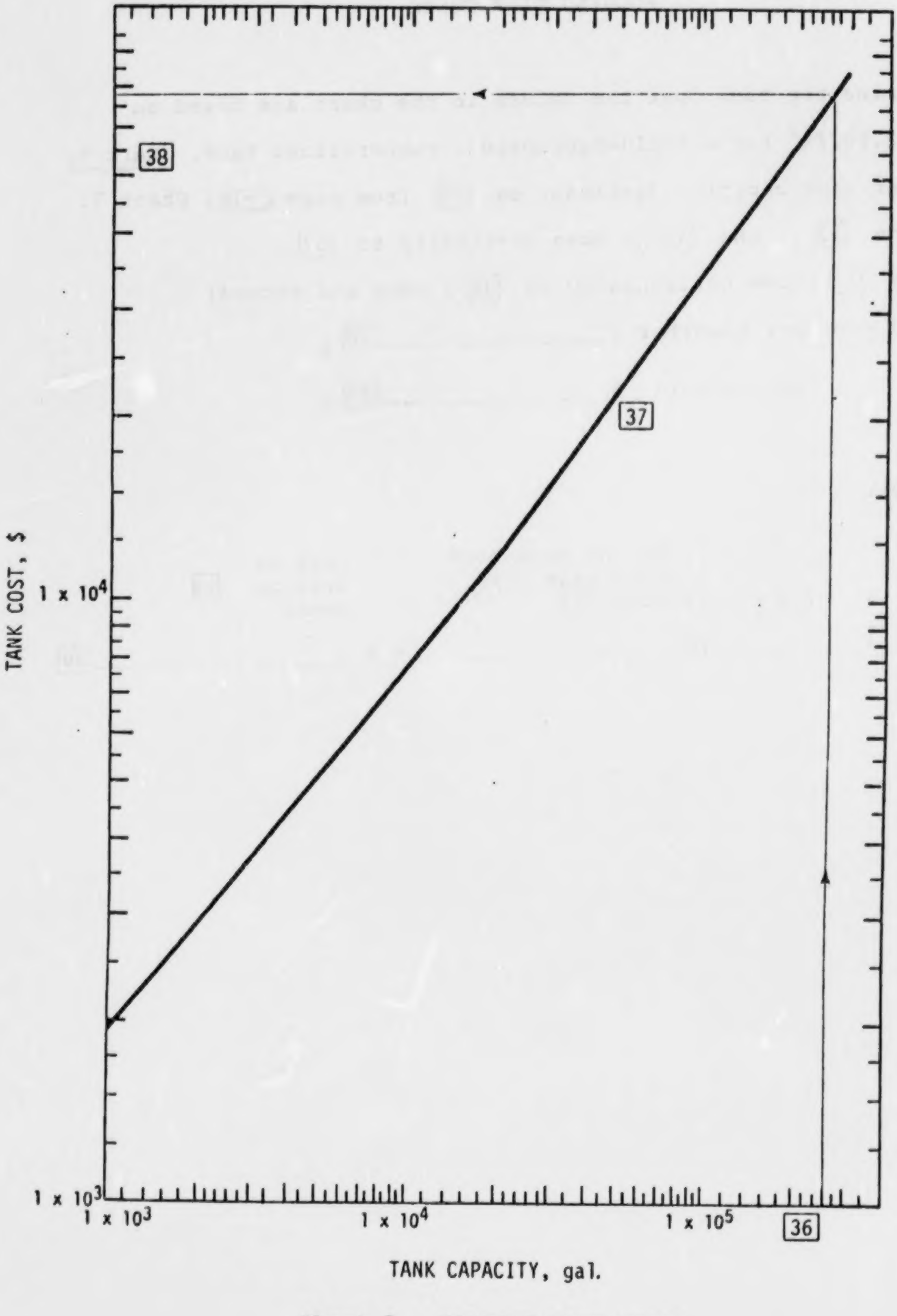


Chart 9. HOLDING TANK COSTS

HOLDING TANK PUMP COSTS

To determine the total pump cost for absorbers and/or venturi, Chart 10:

Enter gpm on $\boxed{40}$ from page C-18, Chart 7, item $\boxed{31}_A$ for the absorber and $\boxed{31}_V$ for the venturi. Select minimum number of pumps, (note 10,000 gpm per pump is maximum), use minimum number of pumps per train and add 1 spare pump per tank. Record number of pumps selected per absorber ________ $\boxed{43}_A$ and per venturi ________ $\boxed{43}_V$

Connect $\boxed{40}$ and $\boxed{41}$ and extend to $\boxed{42}$, read and record:

Flow rate (gpm) per pump ________ absorber; ________ venturi $\boxed{40}_A$; $\boxed{40}_V$

Tabulate:	$\boxed{43}$ No. of pumps	$\boxed{40}$ gpm/pump	$\boxed{25}$ No. of trains	$\boxed{42}$ cost/pump
Absorber	________	________	________	________
Venturi	________	________	________	________

Absorber pump costs:

$(\boxed{43}_A) \times \boxed{25} \times (\boxed{42}_A) = \boxed{44}_A$

(________) x ________ x (________) = $________ $\boxed{44}_A$

Venturi pump costs:

$(\boxed{43}_V) \times \boxed{25} \times (\boxed{42}_V) = \boxed{44}_V$

(________) x ________ x (________) = $________ $\boxed{44}_V$

Pump costs, total: from Chart 11

$\boxed{44}_V + \boxed{44}_A = \boxed{45}$

________ + ________ = $ ________ $\boxed{45}$

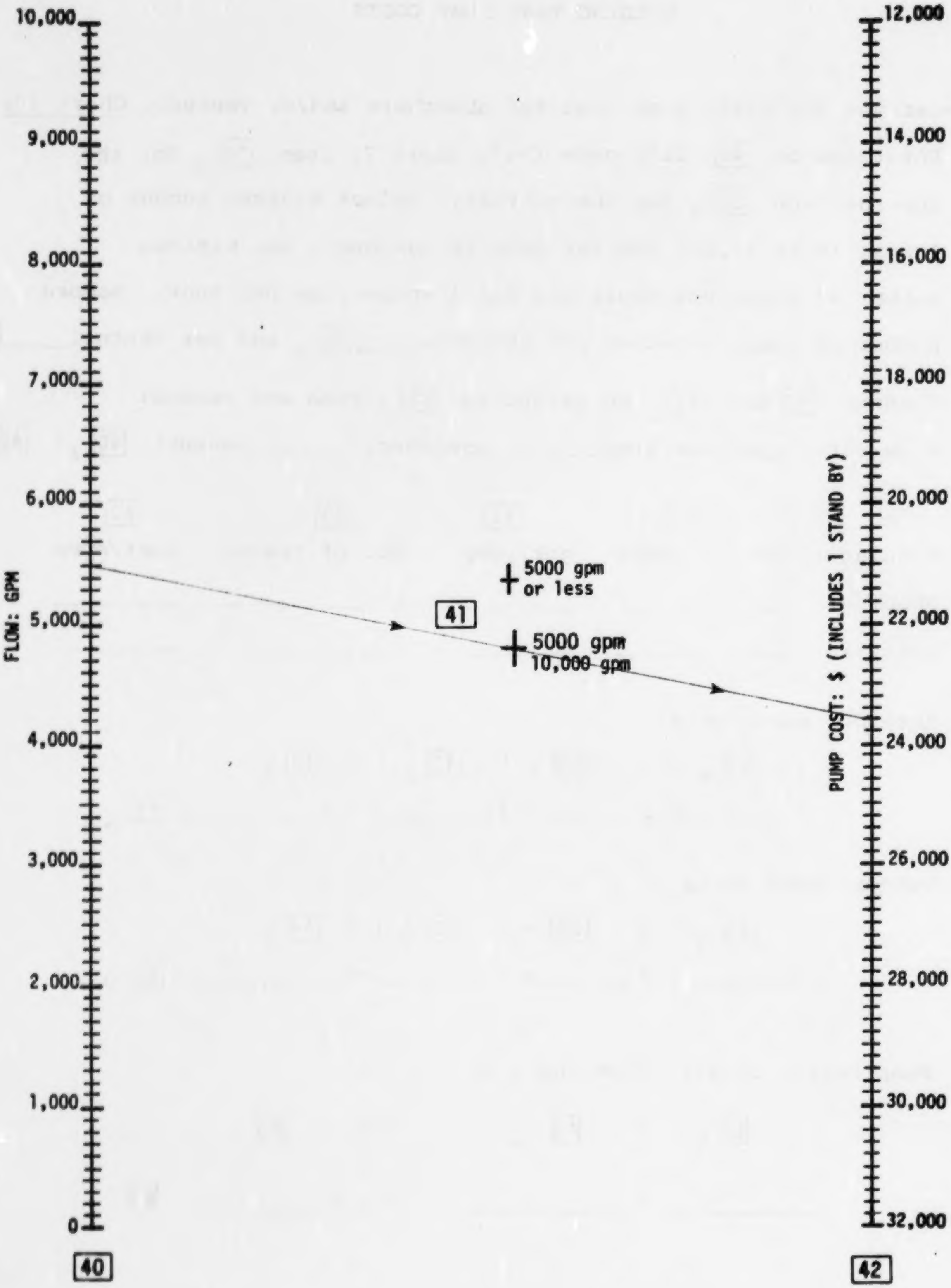


Chart 10. PUMP COSTS

FAN COSTS

To determine fan costs, Chart 11:

Enter acfm at °F of flue gas from the data sheet on $\boxed{46}$

Select appropriate curve for pressure drop* on $\boxed{47}$

Move vertically from $\boxed{46}$ to $\boxed{47}$ and then from $\boxed{47}$ horizontally to $\boxed{48}$ read and record:

Fan costs $____________ $\boxed{48}$

* Typical pressure drop: Absorber 21" (includes 3" safety)
absorber and venturi 31" (includes 3" safety)

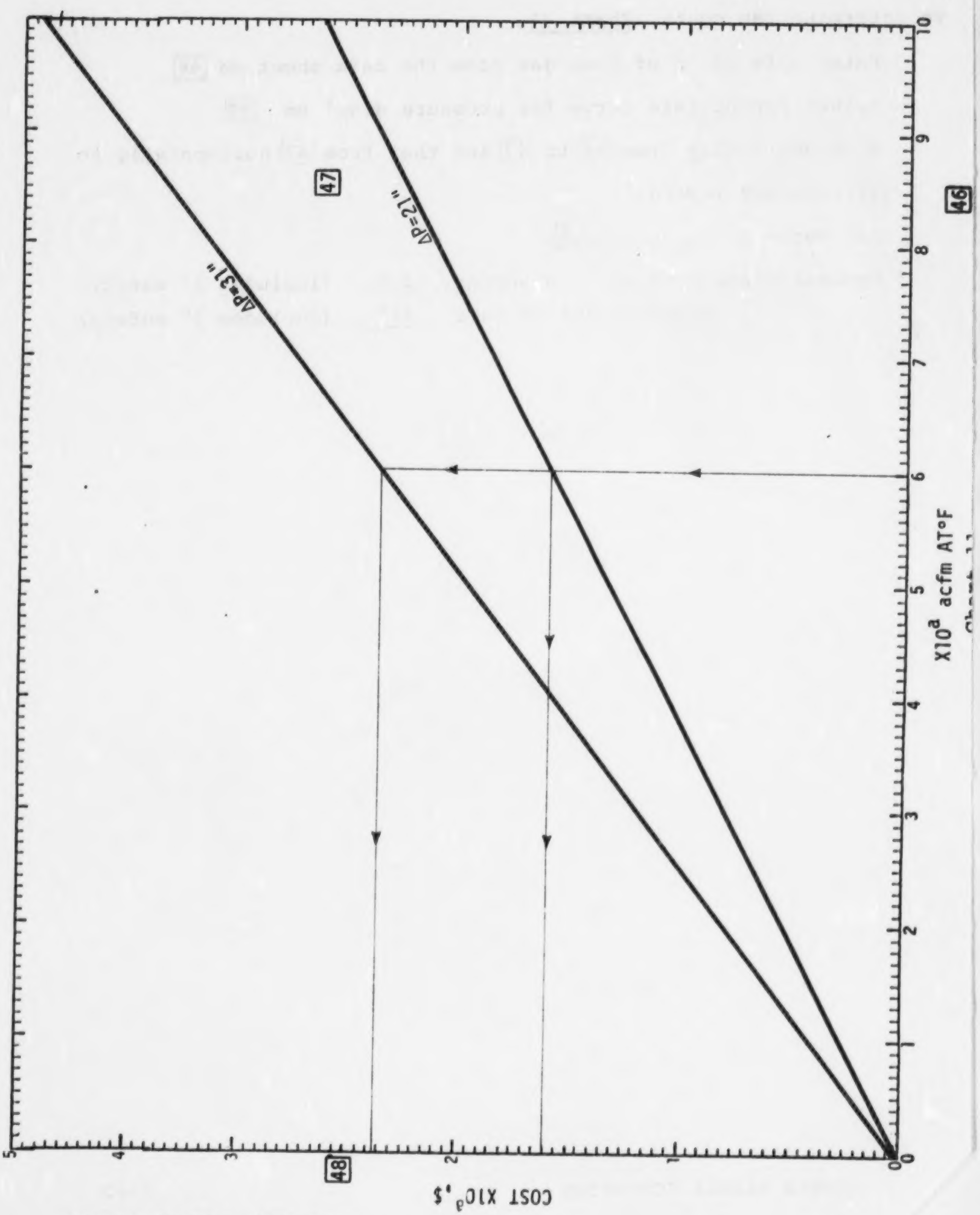

0
1
2
3
4
5
6
7
8
9
10
X10^a acfm AT°F
0
1
2
3
4
5
COST X10^a,$
ΔP=31"
ΔP=21"
46
47
48

Chart 11

HEAT EXCHANGER COST

To determine heat exchanger cost, Chart 12:

Enter item $\boxed{23}$ from page C-16, Chart 6, on Chart 12, item $\boxed{49}$

Move vertically upward to item $\boxed{50}$ for ΔT*

From $\boxed{50}$ move horizontally to the left to $\boxed{51}$, read and record:

Cost for heat exchangers $\$$______________ $\boxed{51}$

* If unknown, use $\Delta T = 50°$

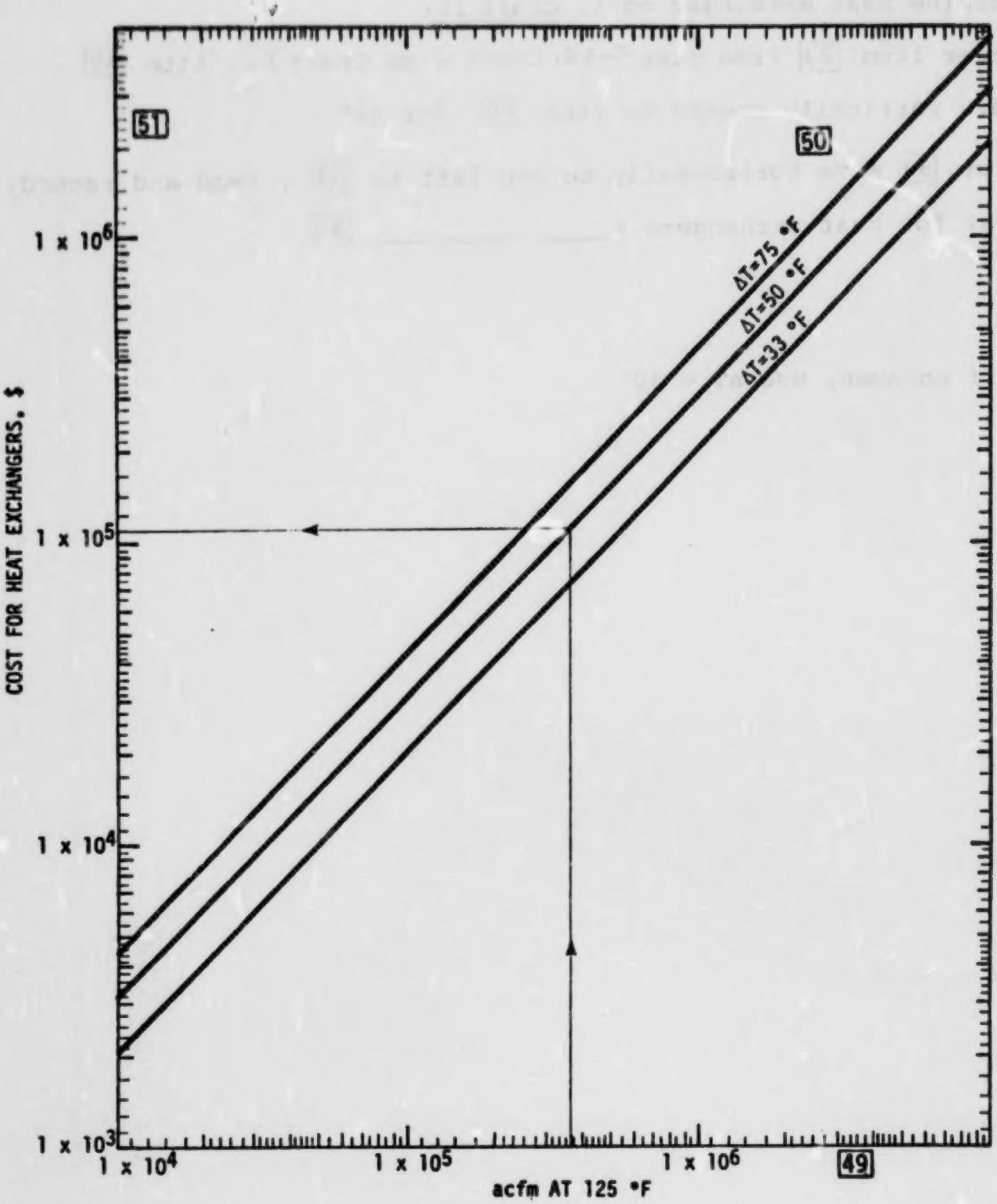


Chart 12. HEAT EXCHANGER COSTS

SOOT BLOWER COST

To determine soot blower cost, Chart 13:

Enter item $\boxed{24}$ from page C-14, Chart 5 on Chart 13, item $\boxed{52}$

Move vertically upward to $\boxed{53}$

From $\boxed{53}$ move horizontally to the left to $\boxed{54}$ and read:

Cost per train . $____________________ $\boxed{54}$

Record from page C-14, Chart 5, item $\boxed{25}$ __________, number of trains

Cost of soot blowers:

$\boxed{54}$ x $\boxed{25}$ = $\boxed{55}$

$_______________ x _____________ = $ _______________ $\boxed{55}$

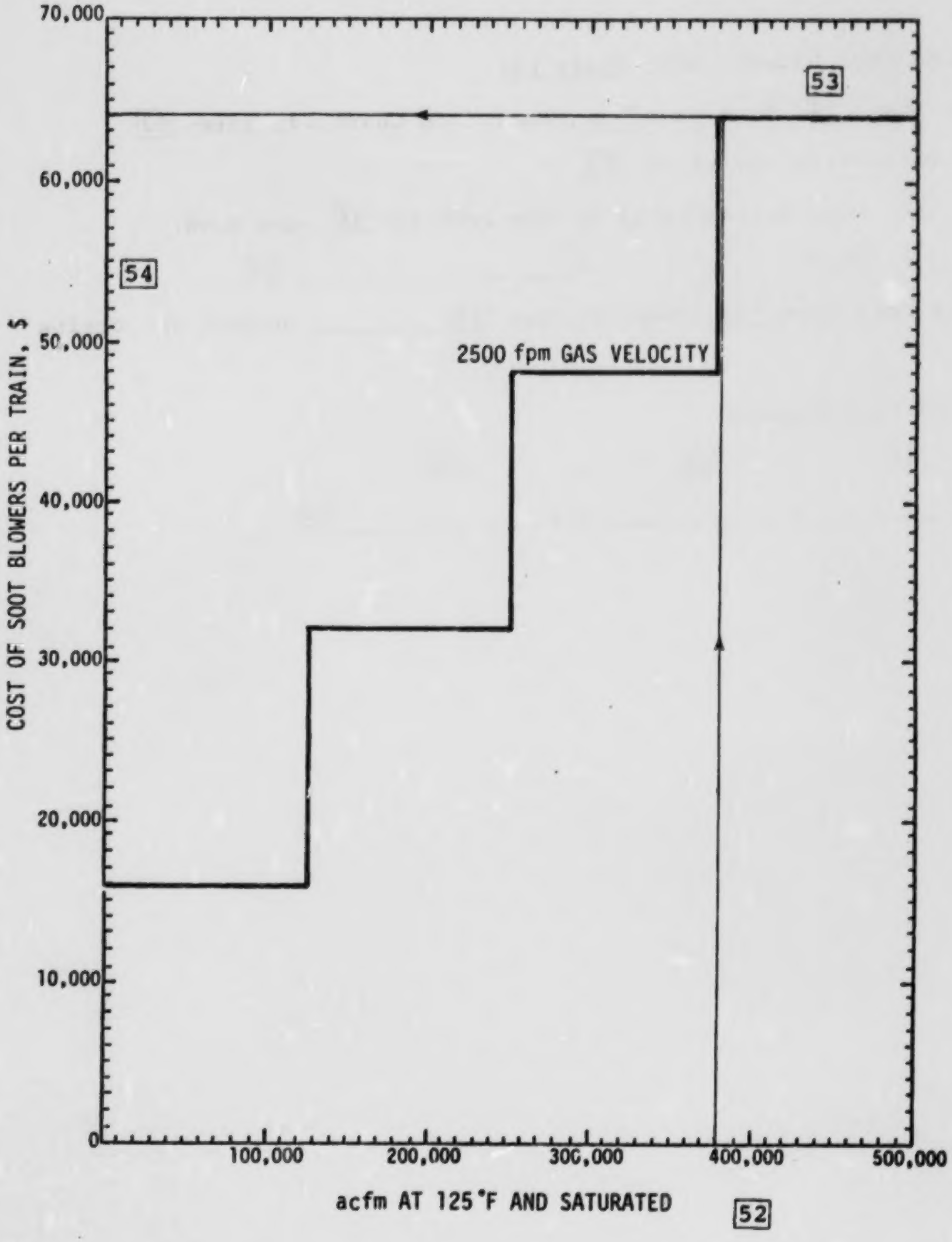


Chart 13. SOOT BLOWER COSTS

REHEAT COST

To calculate the cost of reheat, Chart 14:

Enter acfm at 125°F and saturated of the flue gas from page C-14 Chart 5, item $\boxed{23}$ on Chart 14, item $\boxed{56}$

Select and enter ΔT* of reheat on item $\boxed{57}$

Connect items $\boxed{56}$ and $\boxed{57}$ and extend to item $\boxed{58}$ record ________ $\boxed{58}$

Enter costs ($/MM BTU) reheat** from calculation below on item $\boxed{59}$

Connect items $\boxed{58}$ and $\boxed{59}$ and extend to item $\boxed{60}$, read and record:

Cost ($/hr) reheat ____________________ $\boxed{60}$

Annual reheat cost:

$\boxed{60}$ Weighted capacity factor from data sheet = reheat cost/yr

$ ______________ x 8760 hr/yr x 0.______________ = $ ______________ $\boxed{61}$

*If unknown, use 50% F.
**Reheat Cost -

Coal: To correct from 12,000 BTU/lb and $10/ton

$$= 665 \times \frac{\_\_\_\_\_\_\_\_\ (\$/\text{ton})}{\_\_\_\_\_\_\_\_\ \text{BTU/lb}}$$

= $ ______________ /MM BTU

Oil: To correct from 149,000 BTU/gal. and $10/bbl

$$= 31{,}707 \times \frac{\_\_\_\_\_\_\_\_\ (\$/\text{bbl})}{\_\_\_\_\_\_\_\_\ \text{BTU/gal.}}$$

= $ ______________ /MM BTU

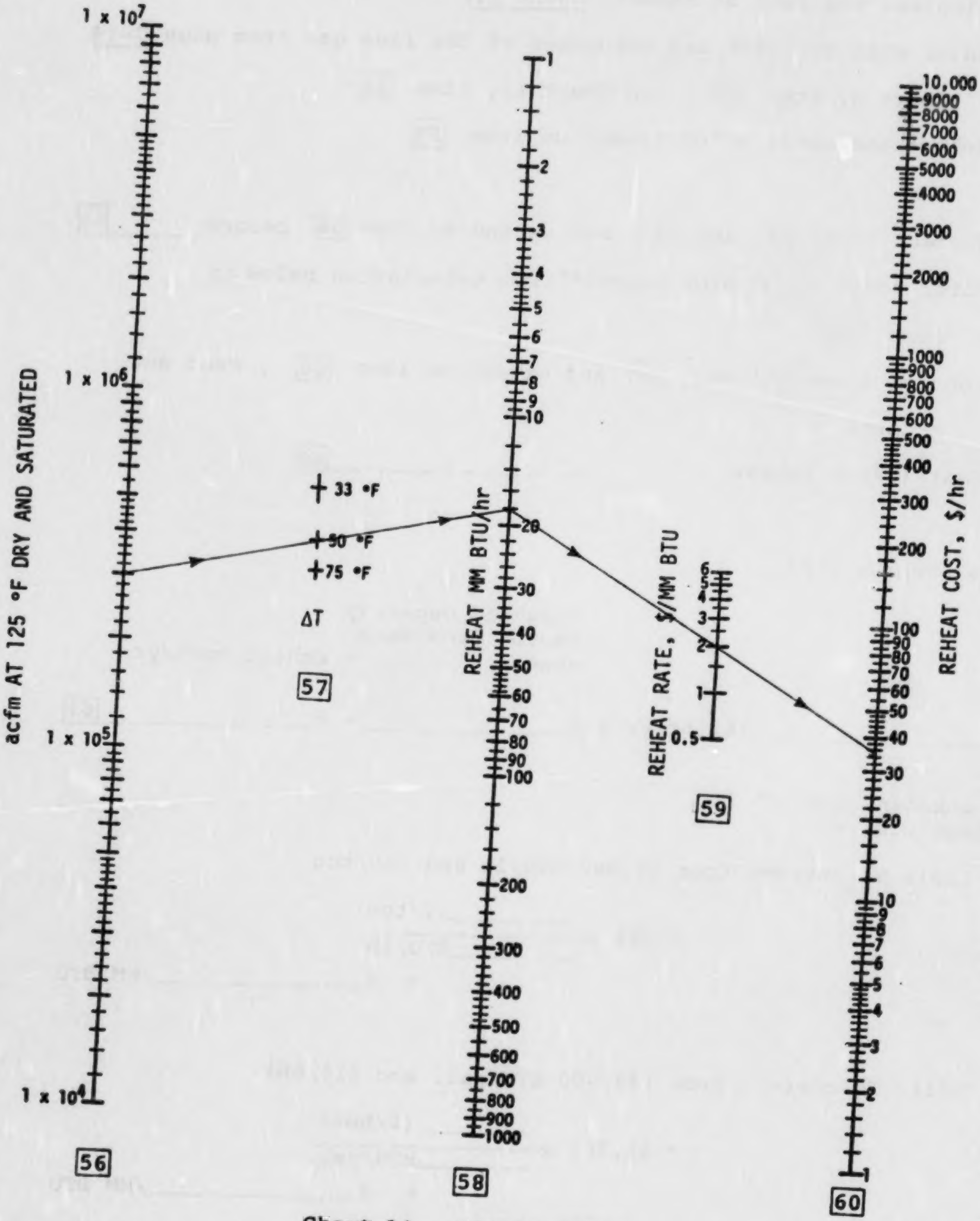


Chart 14. REHEAT COSTS

DUCT COSTS

To calculate ducting cost:

Assumption-

The length of flue duct from the main discharge duct to the venturi (if used) is variable in feet and also the return to the main discharge duct after SO_2 and/or particulate removal. For the specific boiler if more than 1 venturi and/or absorber is required use the multipliers listed in Table 15. Compute each boiler separately, unless identical to each other in absorber or venturi acfm at 125°F and saturated.

From data sheet,
acfm at °F

$$\text{Area duct (from main) in: } \frac{\_\_\_\_\_\_\_\_\_\_}{3{,}500 \text{ ft/min}} = \_\_\_\_\_\_\_\_\_\_ \text{ ft}^2 = 2W^2$$

Perimeter length:

$$\lambda^2 = \frac{\_\_\_\_\_\_\_\_\_\_}{2} = \_\_\_\_\_\_\_\_\_\_ \text{ ft}^2$$

$$\lambda = \sqrt{\_\_\_\_\_\_\_\_\_\_ \text{ ft}^2} = \_\_\_\_\_\_\_\_\_\_ \text{ ft}$$

$$6\lambda = 6x \ \_\_\_\_\_\_\_\_\_\_ \text{ ft} = \_\_\_\_\_\_\_\_\_\_ \text{ ft perimeter}$$

Cost: __________ ft perimeter x 18 lb/linear ft x $0.39/lb =

7.02 x __________ ft perimeter = $_____ cost/linear ft $\boxed{62}$

Page C-14 Chart
5, item $\boxed{23}$

$$\text{Area duct (to main) out: } \frac{\_\_\_\_\_\_\_\_\_\_}{2{,}500 \text{ ft/min}} = \_\_\_\_\_\_\_\_\_\_ \text{ ft}^2 = 2W^2$$

Perimeter length:

$$\lambda = \sqrt{\frac{\_\_\_\_\_\_ \text{ ft}^2}{2}} = \_\_\_\_\_\_\_\_\_\_ \text{ ft}$$

$$6\lambda = 6 \ x \ \_\_\_\_\_\_\_\_\_\_ \text{ ft} = \_\_\_\_\_\_\_\_\_\_ \text{ ft perimeter}$$

Cost: __________ ft perimeter x 18 lb/linear ft x $0.445/lb =

8.01 x __________ ft perimeter = $__________ cost/linear ft $\boxed{63}$

DUCT COST

Table 15. MULTIPLIER FOR DUCT COST

No. of absorbers and/or venturis per boiler	Venturi and absorber in	Venturi or absorber only in	Venturi plus absorber out	Venturi or absorber only out
1	110	70	70	50
2	190	114	113	93
3	250	180	143	123
4	305	225	175	155
5	356	266	205	183
6	410	310	235	208
7	453	346	262	242
8	490	378	288	268
9	535	415	315	295
10	579	452	343	324

* Duct cost in -

(in) cost/linear ft x (Table 15 multiplier + Estimated ft to main duct-(30')) = Duct cost (in) 64

62 $__________ x (__________ + __________ -30) = $__________ 64

**Duct cost out -

(out) cost/linear ft x (Table 15 multiplier + Estimated distance to main duct -(50')) = Duct cost (out) 65

63 $__________ x (__________)+(__________ -50) = $__________ 65

Total duct cost -

64 duct cost (in) + 65 duct cost (out) = total duct cost 66

$__________ + $__________ = $__________ 66

* If congested area add 230 ft for estimated ft.

** If congested area add 200 ft for estimated ft.

FLUE GAS SHUTOFF AND BYPASS VALVES

To calculate flue gas shutoff and bypass valve costs:

Assumption-

Based on 4 vanes/axis in short dimension based on height of 20 ft and width of 10 ft,
Stainless steel at $\$141.6/\text{ft}^2$; carbon steel at $\$99.1/\text{ft}^2$, fabricated

Flue gas valve (in) at main duct to create a bypass

$$\frac{\text{From the data sheet acfm at } \_\_\_\_\ {}^\circ\text{F}}{3{,}500}\Big/\text{Boiler} = \_\_\_\_\_\_\_\_\ \text{ft}^2 = 2\,W^2$$

$$W = \sqrt{\frac{\qquad}{2}\,\text{ft}^2},\ W \times 2 = \_\_\_\_\_\_ \times 2 = \text{height, ft}$$

$$\text{Valve cost A} = (1.5 \times H)\ [(99.1) \pm^{*} (3.1)\ (H-20)\ (0.5H-10)]$$

*H greater than 20 ft, sign is +, less than 20 ft sign is -

$$= (1.5 \times \overset{(H)}{\_\_\_\_})\ [(99.1) \pm (3.1)\ (\overset{(H)}{\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_}-10)]$$

$$= \$\_\_\_\_\_\_\_\_\_\_\_\_ \text{ carbon steel } \boxed{67}$$

Flue gas valve (out) at main duct to create a bypass

$$\frac{\text{Page C-14, Chart 5, item } \boxed{23} \text{ acfm at } \_\_\_\_\ {}^\circ\text{F}}{2{,}500}\Big/\text{Boiler} = \frac{\boxed{23}}{2{,}500} = \_\_\_\_\_\_\_\_\ \text{ft}^2 = 2W^2$$

$$W = \sqrt{\frac{\qquad}{2}\,\text{ft}^2};\ W \times 2 = \_\_\_\_\_\_ \times 2 = \_\_\_\_\_\_ \text{ft (height H)}$$

$$\text{Valve cost B} = (1.5 \times \overset{(H)}{\_\_\_\_})\ [(141.6) \pm^{*} (4.5)\ (\overset{(H)}{\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_}-10)]$$

$$= \_\_\_\_\_\_\_\_\_\_\_\_ \text{ stainless steel } \boxed{68}$$

Flue gas valve (in) to absorber and/or venturi train

$$\frac{\text{Page C-14, Chart 5, item } \boxed{23} \text{ acfm at } \_\_\_\_\ {}^\circ\text{F} \Big/ \text{Boiler}}{\boxed{25} \text{ (No. of venturis or absorbers)} \times 3{,}500} = \text{Area, ft}^2$$

FLUE GAS SHUTOFF AND BYPASS VALVES (continued)

$$\frac{\boxed{23}}{\boxed{25}\_\_\_\_\_\_ \times 3{,}500} = \_\_\_\_\_\_\_\_ = \text{Area, ft}^2 = 2W^2$$

$$W = \sqrt{\frac{\_\_\_\_\_\_}{2}\ \text{ft}^2};\ W \times 2 = \_\_\_\_\_\_\_\_ \text{Height (H), ft}$$

Valve cost C

$$= (\text{Height (H)} \pm 0.5 \text{ Height (H)})\left[(99.1)-(3.1)(H-20)\ (0.5H-10)\right]$$

$$= (1.5 \times \overset{(H)}{\_\_\_\_})\ \left[(99.1)-(3.1)\ (\overset{(H)}{\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_}-10)\right]$$

$= \_\_\_\_\_\_\_\_$ carbon steel $\boxed{69}$

Valve cost D =

$$\left(\frac{\text{Page}}{\text{No. of venturis and/or absorbers}}\right) \times (\text{valve cost}_C\ \boxed{69}) = \boxed{70}$$

$= (\_\_\_\_\_\_) \times (\_\_\_\_\_\_\_) = \$\_\_\_\_\_\_\_\_\_$ $\boxed{70}$

Flue gas valve (out) from absorber and/or venturi

$$\frac{\text{Page C-13, item 25} \atop \text{1.08 acfm at 175°F}}{2{,}500} \Big/ \text{Venturi and/or absorber} = \text{ft}^2$$

$$0.000432 \times \overset{\boxed{24}}{\_\_\_\_\_\_} = \_\_\_\_\_\_ \text{ft}^2 = 2W^2$$

$$W = \sqrt{\frac{\_\_\_\_\_\_}{2}\ \text{ft}^2};\ W \times 2\ \_\_\_\_\_\_ \times 2 = \_\_\_\_\_\_\_\_ \text{ft, (H)}$$

Valve cost$_E$ =

$$= (1.5\overset{(H)}{\_\_\_\_\_\_})\ \left[(141.6)-(4.5)\ (\overset{(H)}{\_\_\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_\_\_}-10)\right]$$

$= \$\_\_\_\_\_\_\_\_\_\_$ stainless steel $\boxed{71}$

Valve cost$_F$ =

$$\left(\frac{\text{Page C-13, item 25}}{\text{No. of venturis and/or absorbers}}\right) \times (\text{valve cost}_E\ \boxed{71}) = \boxed{72}$$

$= (\_\_\_\_\_\_) \times (\_\_\_\_\_\_\_) = \$\_\_\_\_\_\_\_\_\_$ $\boxed{72}$

Valving cost per boiler

$$\text{Valve cost}_G = \boxed{67} + \boxed{68} + \boxed{69} + \boxed{70} = \boxed{73}$$

$$= \quad V_A \quad V_B \quad V_D \quad V_F$$

$$= \_\_\_\_\_\_ + \_\_\_\_\_\_ + \_\_\_\_\_\_ + \_\_\_\_\_\_$$

$= \$\_\_\_\_\_\_\_\_\_\_$ total valve cost $\boxed{73}$

LIME PREPARATION AREA COSTS

To calculate conveyor cost, Chart 16:

Step 1: Estimate distance (ft) from storage silo area to sites and record

_______(ft) $\boxed{74}$ from storage silo area to silos

Step 2: Record from page C-6, item $\boxed{8}_B$

___________lb/hr CaO

lb/hr CaO ÷ 2,000 = ___________ton/hr CaO $\boxed{75}$

Enter ton/hr Chart 16 at $\boxed{75}$ and move vertically upward

to $\boxed{76}$ then move horizontally to the left

to $\boxed{77}$ and record $_____conveyor cost $\boxed{77}_C$

If $\boxed{74}$ is greater or less than 600 ft.

Enter ton/hr at $\boxed{75}$ and move vertically upward

to $\boxed{78}$ and then move horizontally to the left

to $\boxed{77}$ and record $_____conveyor cost/100 ft $\boxed{77}_D$

Number of 100 ft lengths that $\boxed{74}$ is greater or less than 600 ft_____ $\boxed{79}_D$ (estimated by the observer)

$\pm(\boxed{77}_D \times \boxed{79}_D) =$ \$ adjusted cost $\boxed{80}$

± (_________x___________) = $ ±____________ $\boxed{80}$

Conveyor cost:

$\boxed{77}_C \pm \boxed{80} = \boxed{81}$

________ ± ______________ = $ ________conveyor cost $\boxed{81}$

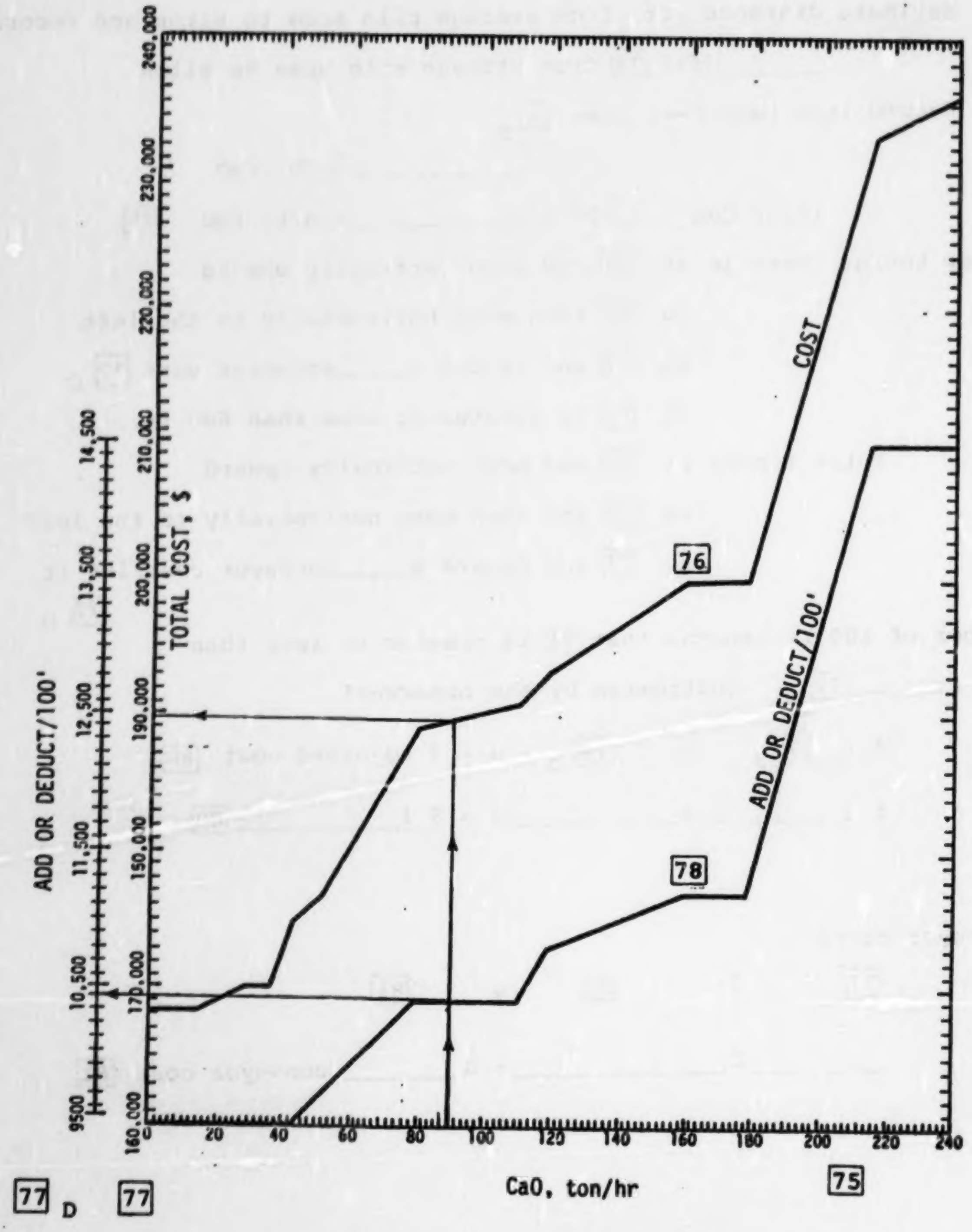


Chart 16. CONVEYOR COSTS

LIME OPERATING AND STORAGE SILO COSTS

To calculate costs of silos for operating 3 day and 12 day storage of lime, Chart 17:

Enter item $\boxed{75}$* from page C-38, Chart 16 on Chart 17, item $\boxed{82}$
then move vertically upward to item $\boxed{83}$
then move horizontally left to item $\boxed{84}$ and read:
Cost for silos for operating 3 days \$______________ $\boxed{84}^{*}_{A}$
Storage silo cost is based on storage capacities indicated:
Enter item $\boxed{75}$ from page C-38, Chart 16 on Chart 17, item $\boxed{82}$
then move vertically upward to item $\boxed{85}$
then move horizontally left to item $\boxed{84}$ and read:
Cost of 12 days storage silo \$______________ $\boxed{84}_{B}$

Fixation silo cost -
1/3 x item $\boxed{84}_{A}$ = \$ cost $\boxed{86}$
0.33 x______________ = \$______________ $\boxed{86}$

__________________ . __________________ . __________________

Lime cost for start-up, 12 day storage plus 3 days operating -

$$\left(\begin{array}{l}\text{Item } \boxed{75} \\ \text{from} \\ \text{Chart 17}\end{array}\right) \text{ x \$25/ton x 24 hours/day x 15 days = \$ costs } \boxed{87}$$

(______________)x 9000 = \$______________________ Lime costs $\boxed{87}$

to correct $\boxed{87}$ for current costs:

$$\boxed{87} \text{ x } \frac{\text{\$/ton current cost CaO}}{25} = \text{\$ corrected costs } \boxed{87}_{C}$$

$$\underline{\hspace{2cm}} \text{ x } \frac{\underline{\hspace{5cm}}}{25} = \underline{\hspace{4cm}}\ \boxed{87}_{C}$$

* If tonnage usage is under 4.7 ton/hr of CaO use the table on following page for storage silo costs.

LIME OPERATING AND STORAGE SILO COSTS (continued)

lb/hr	No. of silos	cost/ ancilliary equipment $\boxed{84}$* A + B
0 - 500	1	9,000
501 - 2,000	1	15,000
2001 - 5,000	2	36,000
5001 - 9,400	3	65,000

________ton/hr $\boxed{75}$ = $ ________ $\boxed{84}$ A+B

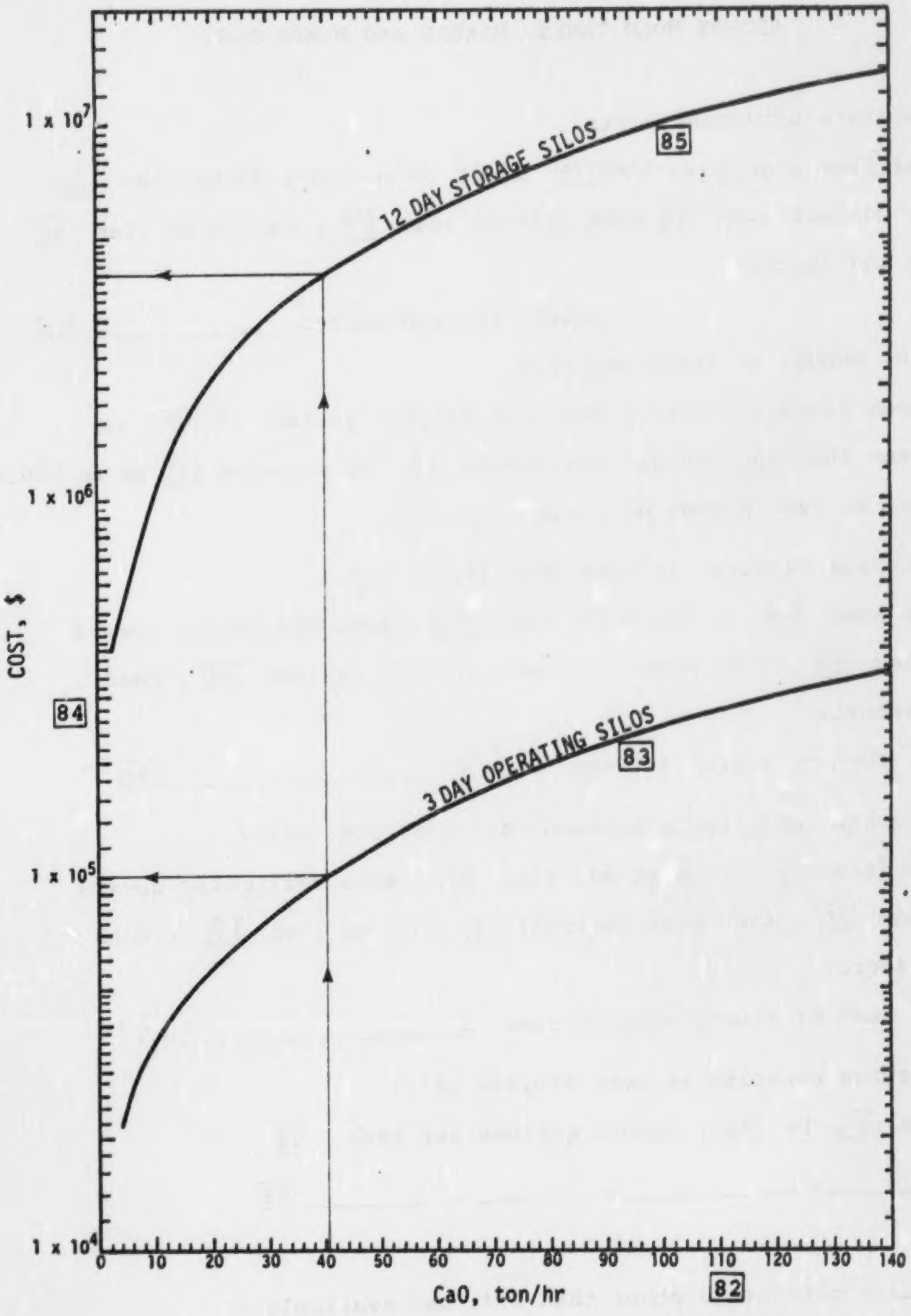


Chart 17. LIME OPERATING AND STORAGE SILO COSTS

SLURRY HOLD TANKS, MIXERS AND PUMPS COST

To calculate slurry tank costs

Enter from page C-38, item $\boxed{75}$ Chart 16 on Chart 18 on item $\boxed{88}$, then connect item $\boxed{88}$ with 15%* on item $\boxed{89}$, extend to item $\boxed{90}$, read and record:

slurry storage gallons________________ $\boxed{90}$

Select number of tanks required:

Maximum storage capacity per tank 600,000 gallons if $\boxed{90}$ is greater than 600,000 gallons, divide $\boxed{90}$ by a number $\boxed{91}$ up to 600,000 to get an even number of tanks_______ $\boxed{92}$

If storage capacity is less than 34,170 gal.:

Enter item $\boxed{90}$ on Chart 19, item $\boxed{92}$, move vertically upward to item $\boxed{93}$, then move horizontally left to item $\boxed{94}$, read and record:

Total cost of slurry storage tank $________________ $\boxed{94}$ **

If storage capacity is between 34,170-600,000 gal.:

Enter item $\boxed{90}$ on Chart 20, item $\boxed{95}$, move vertically upward to item $\boxed{96}$, then move horizontally left to item $\boxed{97}$, read and record:

Total cost of slurry storage tank $________________ $\boxed{97}$ **

If storage capacity is over 600,000 gal.:

Divide $\boxed{90}$ by $\boxed{91}$, record gallons per tank $\boxed{98}$

__________ ÷ __________ = ________________ $\boxed{98}$

*If slurry percentage other than 15%, use available %

SLURRY HOLD TANKS, MIXERS AND PUMPS COST (continued)

Enter item $\boxed{98}$ on Chart 21, item $\boxed{95}$, move vertically upward to item $\boxed{96}$, then move horizontally to item $\boxed{97}$, read and record cost of each tank.

Cost of each slurry tank $________________ $\boxed{97}$ **

Total cost of slurry storage tanks

= cost/tank $\boxed{97}$ x No. of tanks $\boxed{92}$

= ________________ x ________________

= $________________ $\boxed{99}$ **

Mixer cost

From Chart 19, item $\boxed{90}$ ** note the storage capacity required, then select proper range from Table 21, under tank capacity, gal. item $\boxed{100}$ if $\boxed{90}$ is less than 600,000 gal.

No. of mixers________________ $\boxed{102}$

Total mixer costs $________________ $\boxed{103}$

** if item $\boxed{90}$ is greater than 600,000 gallons then enter item $\boxed{98}$ on item $\boxed{100}$ to determine number of mixers required -

No. of mixers/tank____________ $\boxed{101}$

Mixer cost/tank____________ $\boxed{102}$

No. of tanks____________ $\boxed{91}$

Total mixer cost = $\boxed{102}$ x $\boxed{91}$ = $ $\boxed{103}$

________________ x ______ = __________ $\boxed{103}$

SLURRY HOLD TANKS, MIXERS AND PUMPS COST (continued)

Pump cost

Enter from page C-38, item $\boxed{75}$ Chart 16 on Chart 22 on item $\boxed{104}$, then connect item $\boxed{104}$ with slurry % on item $\boxed{105}$, extend to item $\boxed{106}$. Connect item $\boxed{106}$ with 200 ft head on item $\boxed{107}$, extend to item $\boxed{108}$, read and record:

Pump costs/tank $ __________ $\boxed{108}$

Total pump costs = $\boxed{108}$ x $\boxed{91}$ = $ $\boxed{109}$

____________ x ______ = $ __________ $\boxed{109}$

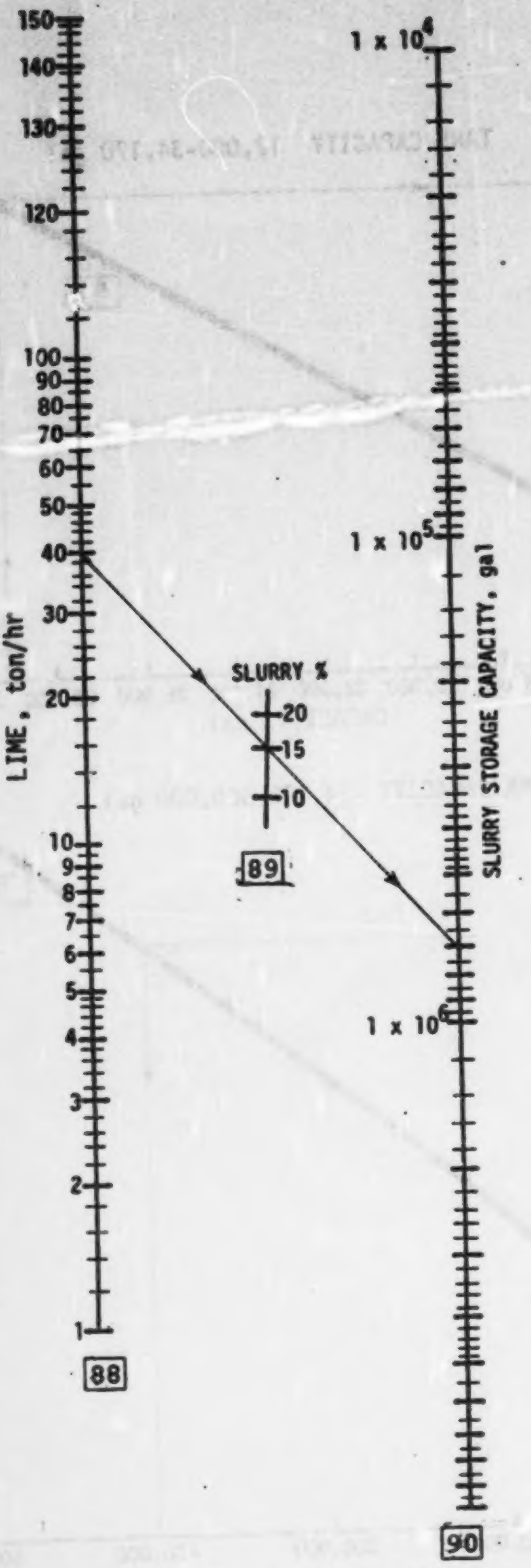
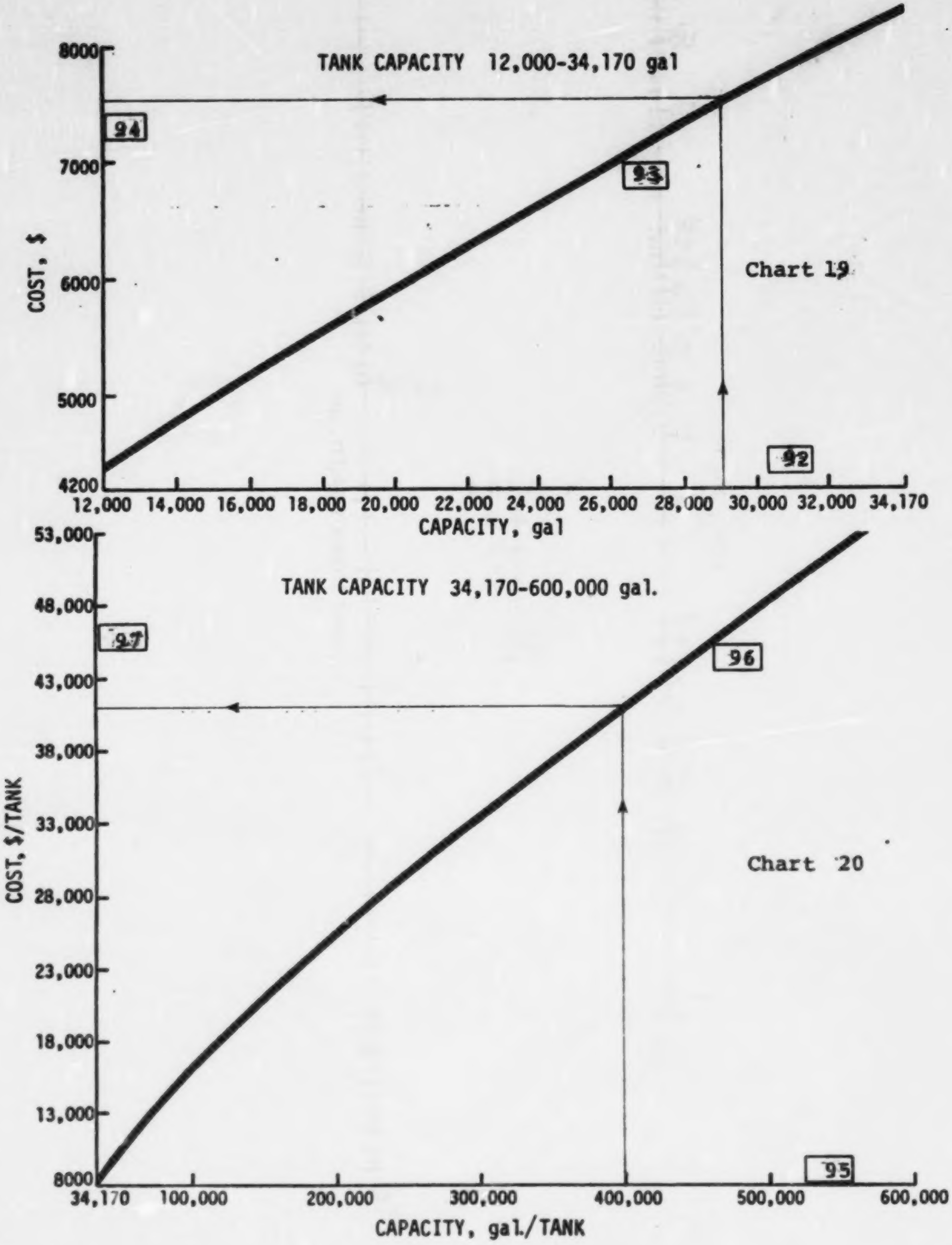


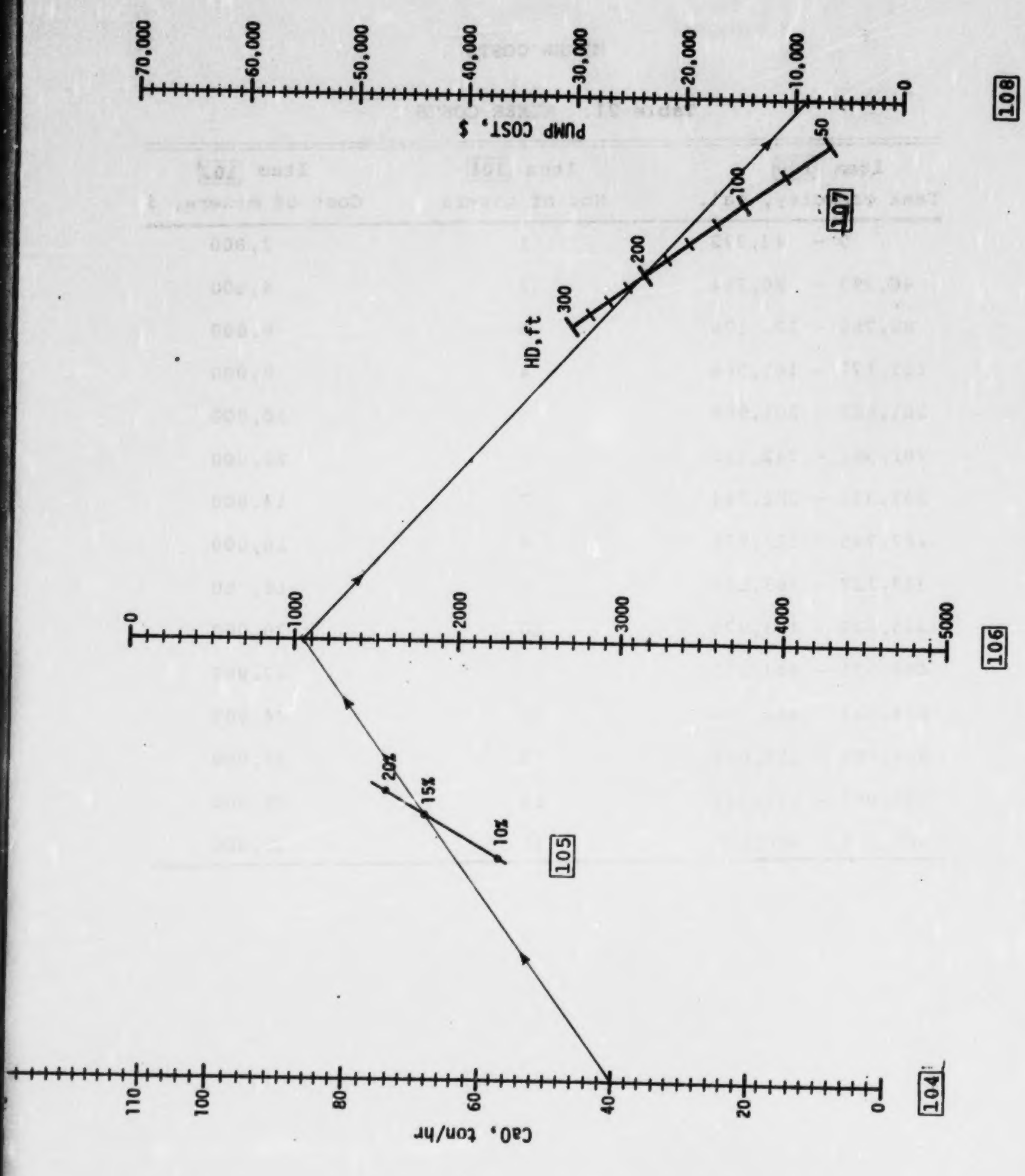
Chart 18. SLURRY TANKS, MIXERS AND PUMPS COST



Charts 19 and 20. SLURRY TANKS, MIXERS AND PUMPS COST

Table 21. MIXER COSTS

Item 100 Tank capacity, gal.	Item 101 No. of mixers	Item 102 Cost of mixers, $
0 - 40,392	1	2,000
40,393 - 80,784	2	4,000
80,785 - 121,176	3	6,000
121,177 - 161,568	4	8,000
161,569 - 201,960	5	10,000
201,961 - 242,352	6	12,000
242,353 - 282,744	7	14,000
282,745 - 323,136	8	16,000
323,137 - 363,528	9	18,000
363,529 - 403,920	10	20,000
403,921 - 444,312	11	22,000
444,313 - 484,704	12	24,000
484,705 - 525,096	13	26,000
525,097 - 565,488	14	28,000
565,489 - 600,000	15	30,000


104
CaO, ton/hr
0
20
40
60
80
100
110
105
10%
15%
20%
106
0
1000
2000
3000
4000
5000
107
HD, ft
50
100
200
300
108
PUMP COST, $
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000

COST OF SLAKER, AND PUMP

To calculate slaker, and pump costs:

Enter from page C-38, item $\boxed{75}$ Chart 16 on Chart 23 on item $\boxed{110}$, move vertically upward to item $\boxed{111}$, then move horizontally left to item $\boxed{112}$ and read:

Slaker and pump cost $______________ $\boxed{112}$

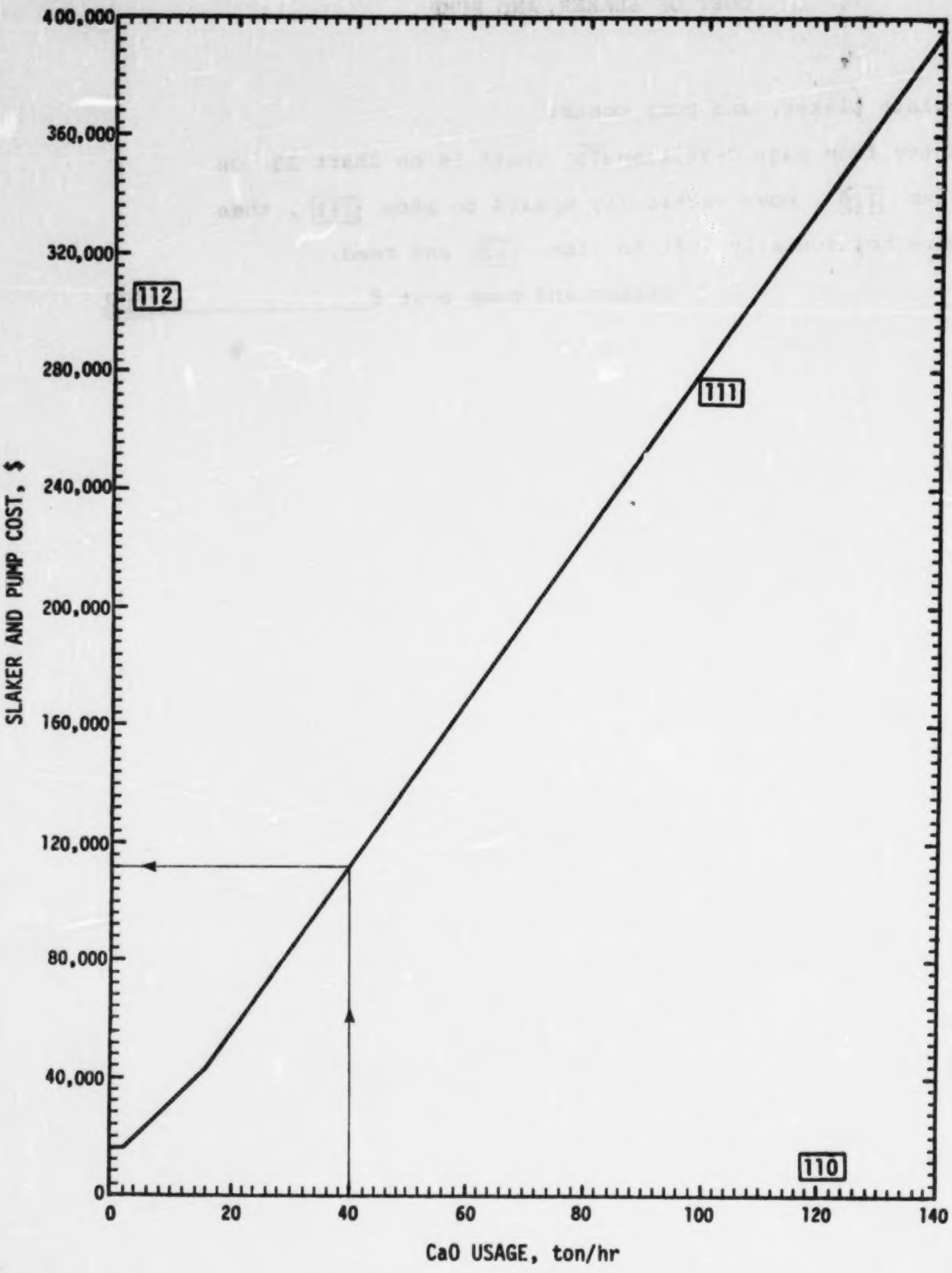


Chart 23. COST OF SLAKER, AND PUMP

REACTOR TANK COSTS

To determine reactor tank costs, Charts 24 and 25

From page C-5, item $\boxed{5}$ ______ lb/MM BTU of SO_2 $\boxed{113}$

From data sheet, maximum continuous heat input ______ MM BTU/hr $\boxed{114}$

Multiply : $\boxed{113}$ x $\boxed{114}$ = $\boxed{115}$ lb SO_2/hr

______ x ______ = ______ $\boxed{115}$

Enter item $\boxed{115}$ on $\boxed{116}$ on Chart 24

Select appropriate point* for % solids on $\boxed{117}$, join $\boxed{116}$ and $\boxed{117}$ and extend to $\boxed{118}$ and read

Lime slurry, gpm ______ $\boxed{118}$

From the same point on $\boxed{116}$ go through pivot point $\boxed{119}$ to $\boxed{120}$ and read

Absorber underflow, gpm ______ $\boxed{120}$

Total reactor flow gpm = lime slurry gpm + absorber underflow gpm

$\boxed{118}$ $\boxed{120}$

= ______ + ______ = ______ $\boxed{121}$

Enter $\boxed{121}$ on Chart 25 on $\boxed{122}$, select retention time** on $\boxed{123}$

Connect $\boxed{122}$ and $\boxed{123}$ and extend to $\boxed{124}$ and read

Total reactor capacity, gal. ______ $\boxed{124}$

Also read No. of tanks ______ $\boxed{125}$

If number of tanks at $\boxed{125}$ is 3 or less, add 1 stand-by tank; if number of tanks at $\boxed{125}$ is 3 or more, add 2 stand-by tanks to obtain actual number of tanks ______ $\boxed{126}$

Actual No. of tanks $\boxed{125}$ + stand-by tanks = $\boxed{126}$

= ______ + ______ = $\boxed{126}$

* If unknown, use 15% Solids

** If unknown, use 30 Min.

REACTOR TANK COSTS (Continued)

Capacity of each reactor, gal. = $\frac{\boxed{124}}{\boxed{125}}$ = ______________ $\boxed{127}$

Reactor agitator cost: Table 8

Enter $\boxed{127}$ in tank capacity, gal. on page C-19, Chart 8 and record Agitator cost/reactor = $______________ $\boxed{128}$

Reactor tank cost: Chart 9

Enter item $\boxed{127}$ on page C-22, Chart 9, item $\boxed{36}$ and move vertically to $\boxed{37}$ then horizontally to $\boxed{38}$, record tank cost

= $______________ $\boxed{129}$

Reactor cost = Tank cost + Agitator cost

$\boxed{129}$ $\boxed{128}$ $\boxed{130}$

= ______________ + ______________ = ______________

Total reactor costs = Cost/Reactor x No. of Reactors

$\boxed{130}$ x $\boxed{126}$ = Total reactor costs

= ______________ x ______________ = $______________ $\boxed{131}$

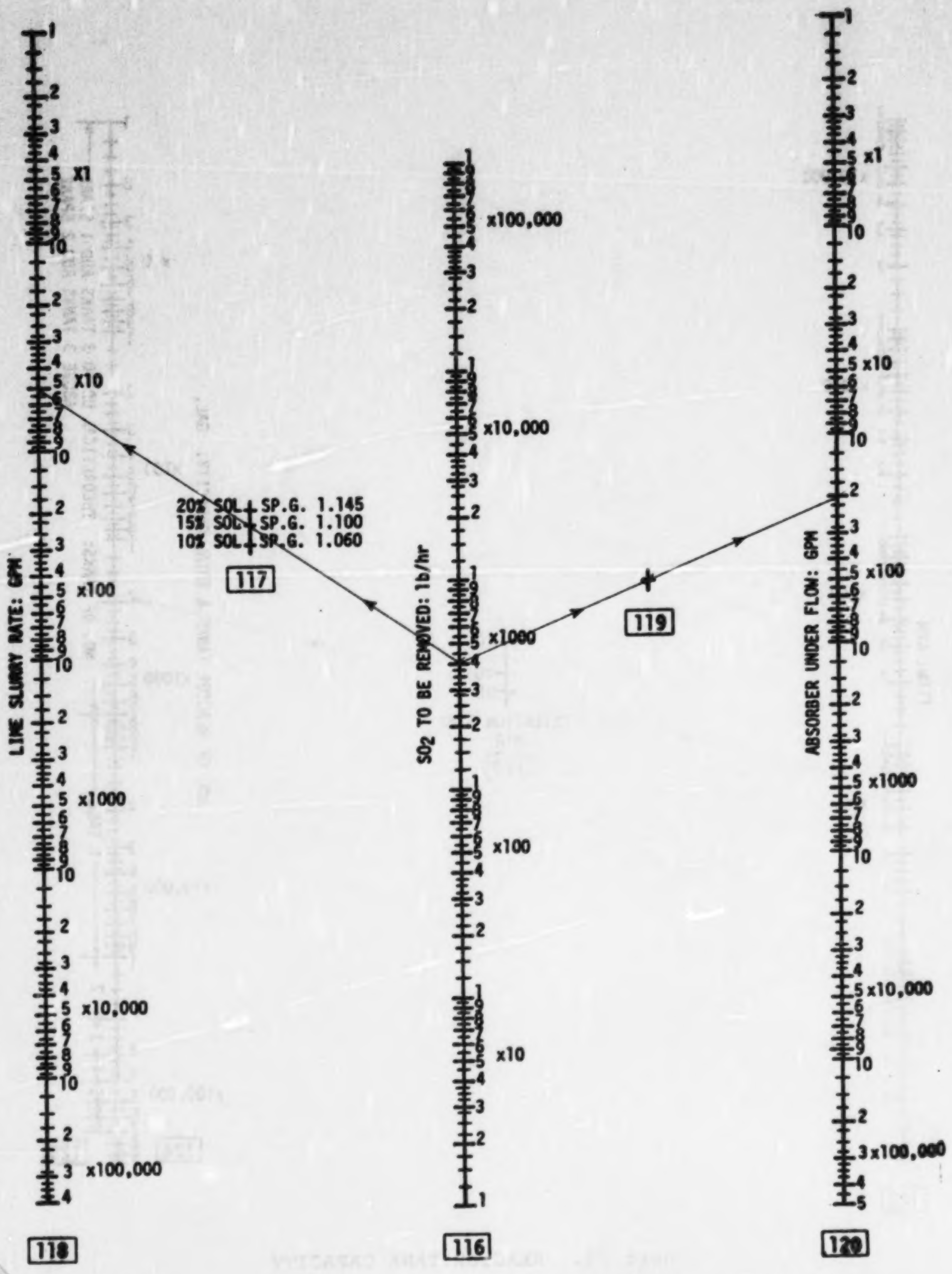


Chart 24. REACTOR FLOW

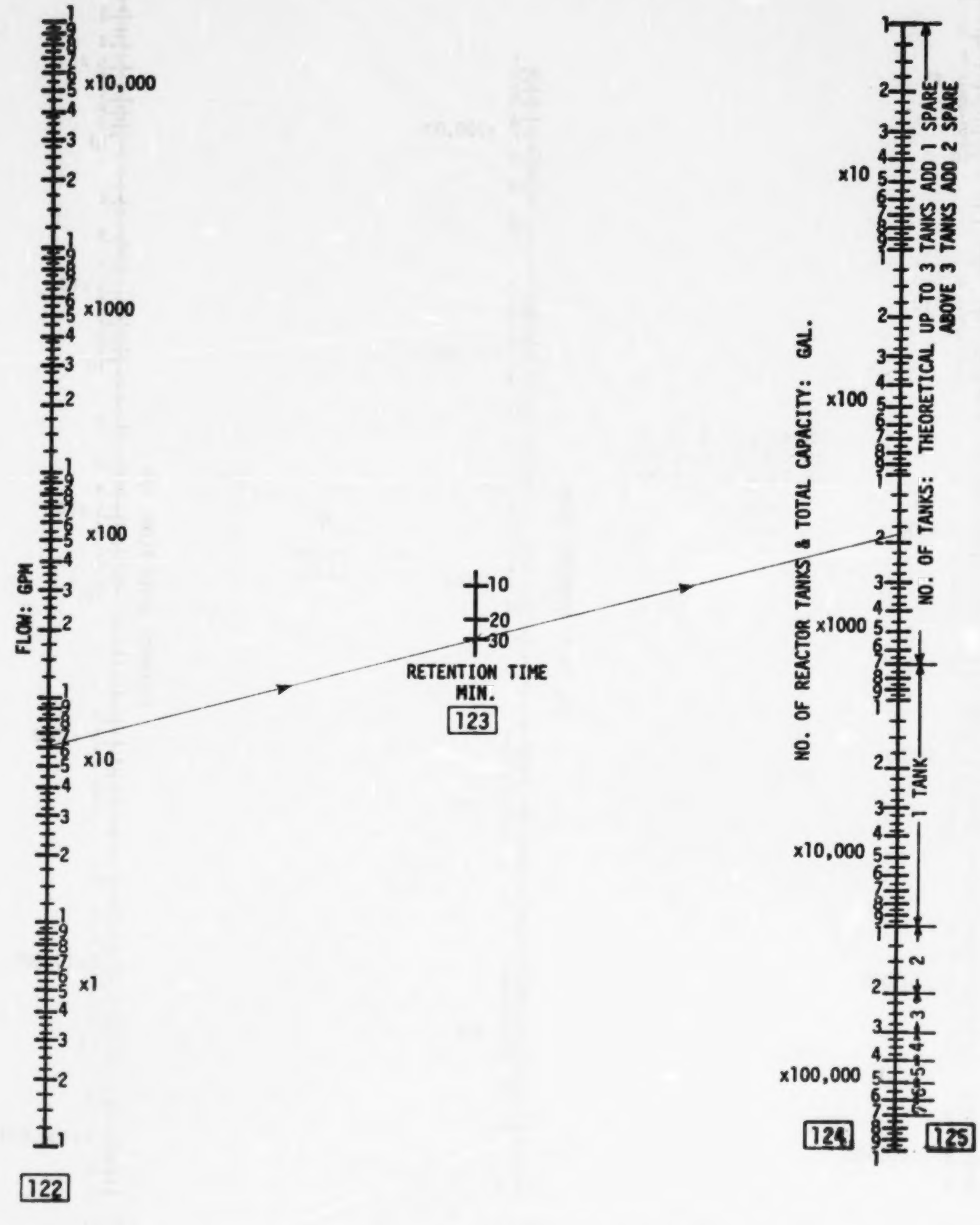


Chart 25. REACTOR TANK CAPACITY

SODA ASH STORAGE AND OPERATING SILOS COSTS

From page C-9, item $\boxed{13}$ ____________ lb/MM BTU of Soda Ash $\boxed{132}$

From data sheet, maximum continuous heat input ____________ MM BTU/hr $\boxed{133}$

$\boxed{132} \times \boxed{133} = \boxed{134}$ lb Soda Ash/hr

__________ x ____________ = _________________ $\boxed{134}$

Soda Ash ton/hr = $\frac{\boxed{134}}{2000} = \frac{\overset{\boxed{134}}{\rule{3cm}{0.4pt}}}{2000}$ = ______________ ton/hr $\boxed{135}$

Enter item $\boxed{135}$ ** on Chart 17 on $\boxed{82}$ and move vertically upward to item $\boxed{83}$, then move horizontally to $\boxed{84}$ and read

Cost of operating silos = $________________ $\boxed{136}$ A

Storage Silo Costs:

Enter item $\boxed{135}$ on Chart 17 on $\boxed{82}$ then move vertically upward to $\boxed{85}$, then move horizontally to the left to $\boxed{84}$ and read

Cost of 12 day Storage Silos = $________________ $\boxed{136}$ B

Soda Ash Cost for Start-up: (12 day storage + 3 day operation)

$\boxed{135}$ x cost of Soda Ash $/ton* x 24 x 15 =

$\boxed{135}$

__________________ x ____________ x 360 = $__________________ $\boxed{137}$

* Obtain from data sheet.

** If $\boxed{135}$ is less than 4.7 ton/hr use the table below for Storage Silo Costs:

lb/hr of Soda Ash	$ $\boxed{138}$ A + B
0 - 500	9,000
501 - 2000	15,000
2001 - 5000	36,000
5001 - 9400	65,000

SOLID DISPOSAL

To find the cost of clarifier and vacuum filtration equipment and pump combined, Chart 26:

Chart 26 gives the cost of the following system and limitations:

Clarifier 150 ft diameter

Overflow pump head, 250 ft

Under flow pump head, 250 ft

Filtrate-return pump head, 350 ft

Sludge pump head 1000 ft

Under flow emergency pump

Vacuum filter, 50 ton/hr

Sludge mix tank and mixer

Water make-up pump

Enter item $\boxed{17}$A (dry sludge, ton/hr), from page C-12 Chart 4 on 139

Select number of clarifier units, same size (each 50 ton/hr of dry sludge requires 1 clarifier unit) =______units $\boxed{140}$

From item $\boxed{139}$ move vertically upward to item $\boxed{141}$ (Bhp system curve), then continue upward to item $\boxed{142}$ (equipment cost curve).

From item $\boxed{141}$ move horizontally to the right to item $\boxed{143}$ for hp of equipment.

$\boxed{143}$ x $\boxed{140}$

hp of equipment x No. of units = total hp required=______x______= ________hp $\boxed{144}$

From item $\boxed{142}$ move horizontally to the left to item $\boxed{145}$ for equipment, $__________/unit $\boxed{145}$

Item $\boxed{145}$ x item $\boxed{140}$ = total cost $\boxed{146}$

__________x________________= $__________ $\boxed{146}$

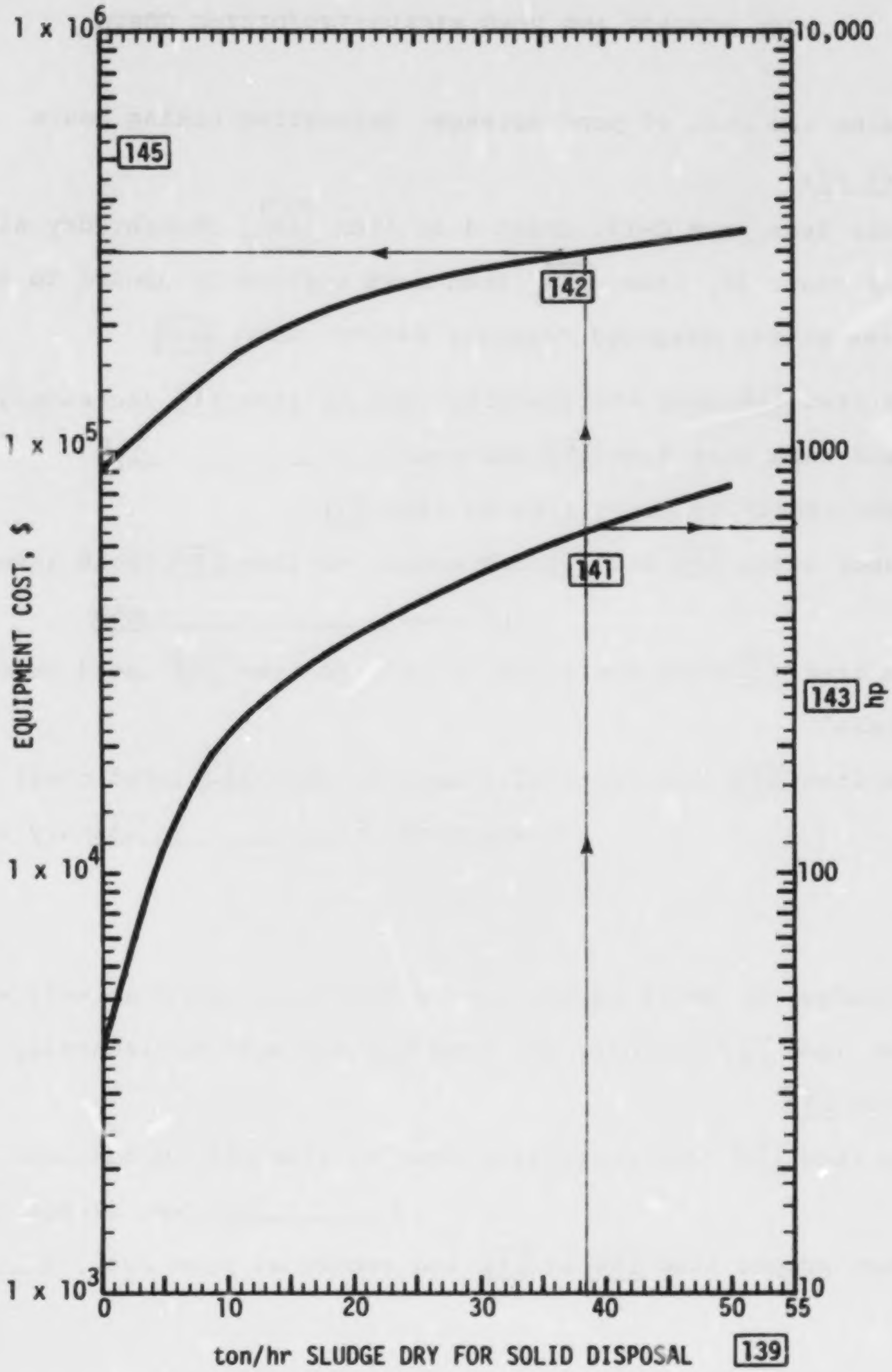


Chart 26. SOLID DISPOSAL COSTS

POND ACREAGE AND POND EXCAVATING/DIKING COSTS

To determine the cost of pond acreage, excavating/diking costs,

Chart 27:

Enter from page C-12, Chart 4 on item $\boxed{16}_A$ (ton/hr dry sludge) on Chart 26, item $\boxed{147}$ then move vertically upward to the respective weighted capacity factor, item $\boxed{148}$

From item $\boxed{148}$ move horizontally left to item $\boxed{149}$ (acre-ft/yr) and reference line $\boxed{150}$ and read:________________ $\boxed{149}$

Select remaining plant life on item $\boxed{151}$

Connect items $\boxed{150}$ and $\boxed{151}$ and extend to item $\boxed{152}$ (pond acre-ft) and read:________________ $\boxed{152}$

From item $\boxed{152}$ move horizontally left to item $\boxed{153}$ (pond reference scale)

From item $\boxed{153}$ move vertically down to item $\boxed{154}$ (pond cost) and read: \$ ______________ $\boxed{154}$ dry sludge

If wet sludge, no waste return 1.67 x $\boxed{152}$ =_______pond acre-ft wet sludge $\boxed{15}$

Enter item $\boxed{155}$ on Chart 27 item $\boxed{152}$ and move horizontally left to item $\boxed{153}$

From item $\boxed{153}$ move vertically down to item $\boxed{154}$ (pond cost) and read: \$ ________ $\boxed{156}$ wet sludge pond cost

Select proper item $\boxed{154}$ or $\boxed{156}$ and record as pond cost, \$__________ $\boxed{157}$

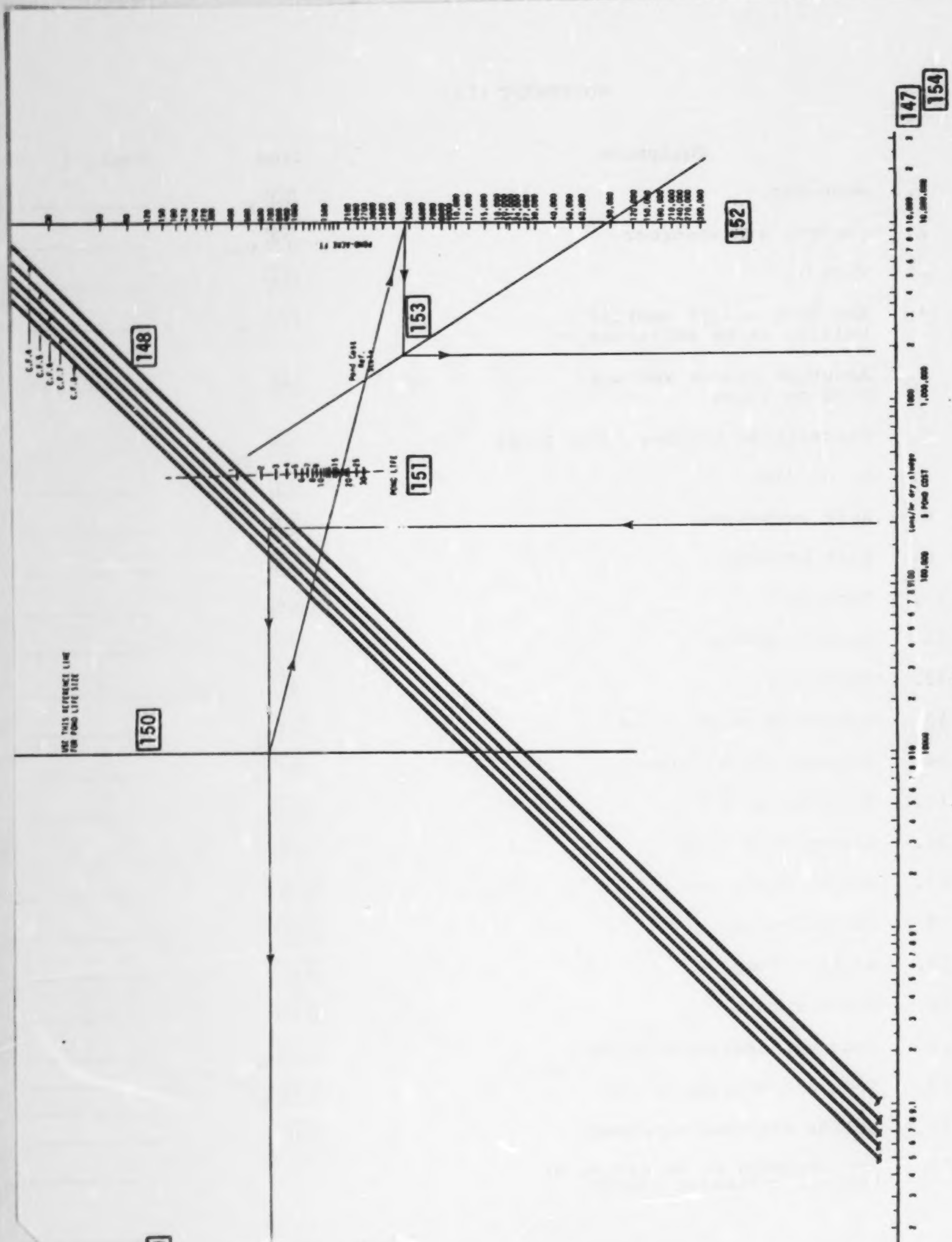


Chart 27. POND COST

EQUIPMENT COST

	Equipment	Item	Cost, $
1.	Absorber	28 A	
2.	Venturi and absorber	28 V+A	
3.	Venturi	28	
4.	Absorber and/or venturi holding tanks agitators	35 T	
5.	Absorber and/or venturi holding tanks	39 T	
6.	Circulation holding tanks pumps	45 T	
7.	I. D. fans	48	
8.	Heat exchangers	51	
9.	Soot blowers	55	
10.	Ducting	66	
11.	Bypass valving	73	
12.	Conveyors	81	
13.	Operating silos, Lime	84 A	
14.	Storage silos, Lime	84 B	
15.	Fixation silo	86	
16.	Slurry hold tanks	94	
17.	Slurry agitators	103	
18.	Slurry pumps	109	
19.	Slaker, Pump	112	
20.	Reactor tank	131	
21.	Soda ash operating silos	136 A	
22.	Soda ash storage silos	136 B or 138	
23.	Solids disposal equipment	146	
24.	New roadways or RR siding at $50/ft, estimated length		

Total equipment cost $ ____________

Total equipment cost from page C - 60 ______________

Year of FGD system operation

Select from cost factor index multiplier from page C- 62, for the year above________

Predicted costs:

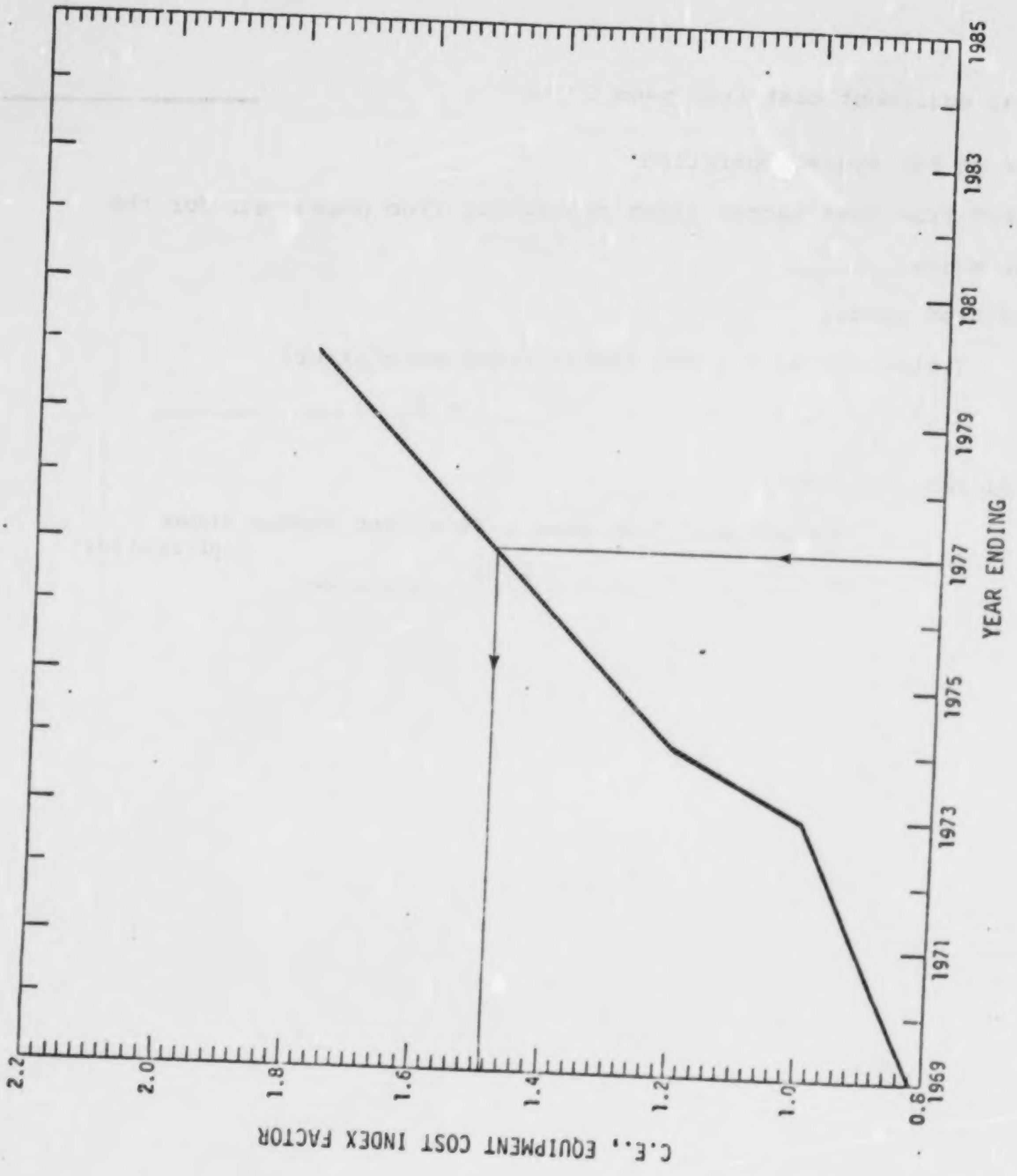
(total costs) x (cost factor index multiplier)

(___________) x (_______________) = $_________________

Predicted pond cost

= Pond cost from page C-58 x Cost factor index multiplier

= _______ x _______ = $ __________


C.E., EQUIPMENT COST INDEX FACTOR
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
YEAR ENDING
1969
1971
1973
1975
1977
1979
1981
1983
1985

CAPITAL INVESTMENT COSTS

Direct costs:

Select system required	Absorber	Absorber & venturi	Cost,$
"A" Material	2.08 λ^a	2.07 λ	
"B" Labor	1.27 λ	1.28 λ	
	Materials and labor		
"C" Retrofit	Absorber	Absorber-venturi	
Easy	0	0	
Moderate	0.047λ	0.039λ	
Difficult	0.093λ	0.077λ	

[a] λ = Equipment cost predicted from page C-61

"A" + "B" + "C" = $______________

"D" Raw materials: item $\boxed{87}$ plus item $\boxed{137}$

"E" Predicted Pond costs page C-61 = $______________

"F" Direct costs ("A" + "B" + "C" + "E") above = $______________

"G" Direct costs ("A" to "E" inclusive) = $______________

"H" Direct costs ("A" + "B" + "C") above = $______________

Indirect costs:

"J" Interest (at 8%), contractor fees and expenses, engineering, freight, off-site, taxes, start-up, spares -

(0.33 "G") + (0.1 "H") + (0.065 "F") =

(0.33 x______) + (0.1 x_______) + (0.065 x_______) = $______________

"K" Contingency:

0.2 ("J" + "F") = 0.2 (_________+_________) = $______________

"L" Total costs for capital investment

"G" + "J" + "K" =_________+_________+_________

= $______________

Cost/Kilowatt:

$$\frac{L}{\text{MW's} \times 1{,}000} = \frac{\_\_\_\_\_\_\_\_\_\_}{\_\_\_\_\_ \times 1{,}000} =$$

$____________/KW

TOTAL ANNUAL OPERATING COSTS

Utilities -

Water: Na+ scrubbing

64 gal./MW for 3.0% S coal $\boxed{158}$

±Δ5.5 gal./MW for each ± 1.0% S in coal $\boxed{159}$

52 gal./MW for 2.0% S oil $\boxed{160}$

±Δ-4 gal./MW for each ± 1.0% S in oil $\boxed{161}$

Limestone:

(gal./MW ± gal./MW corr. for % S) x hr/yr x weighted capacity factor x water costs/1,000 gal. = Yearly cost water/MW $\boxed{162}$

($\boxed{158}$ or $\boxed{160}$ ± $\boxed{159}$ or $\boxed{161}$) x C.F.

(____________ ± ____________) x ________ x 8760 x $\frac{\$0.02}{1{,}000 \text{ gal.}}$ = $/MW

$____________ $\boxed{162}$

(Coal or oil); (Base; % S % S corr.) ; $\boxed{162}$ x MW = $\boxed{163}$

(__________);(______ ; ______); __________ x ____________ = $__________/yr $\boxed{163}$

Reheat:

From page C-39, item $\boxed{61}$ determine $/reheat
(see calculation sheet)

$________________/yr $\boxed{61}$

For ΔT ______°F

TOTAL ANNUAL OPERATING COSTS

Operating labor cost:

MW's	Men/Shift
100- 699	3.16
700-1200	3.33
1201-2500	4.5
2501-	5.33

$$\text{Men/shift x hr/yr x \$/hr} = \boxed{164}$$

$$\_\_\_\_\_\_\_\_\_\_ \text{ x } 8760 \text{ x } 6.50 = \boxed{164}$$

$$\_\_\_\_\_\_\_\_\_\_ \text{ x } 56{,}940 = \$\_\_\_\_\_\_\_\_\_\_\text{/yr} \qquad \boxed{164}$$

$$\text{Corrected cost: } \boxed{164} \text{ x}\left(\frac{\text{\$/hr (manpower)}}{6.50}\right) = \$\_\_\_\_\_\_\_\_\text{/yr} \qquad \boxed{164}_c$$

Supervision:

$$0.15 \text{ x } 56{,}940 \text{ x men/shift} = \boxed{165}$$

$$8541 \text{ x}\_\_\_\_\_\_\_\_\_\_ = \$\_\_\_\_\_\_\_\_\_\_\text{/yr} \qquad \boxed{165}$$

$$\text{Corrected cost: } \boxed{164}_c \text{ x } 0.15 = \$\_\_\_\_\_\_\_\_\_\_\text{/yr} \qquad \boxed{165}_c$$

Maintenance:

Capital costs, total

$$0.046 \text{ x}\_\_\_\_\_\_\_\_\_\_\_\_\_\_ = \$\_\_\_\_\_\_\_\_\_\_\text{/yr} \qquad \boxed{166}$$

Overhead:

Capital cost, total + Men/shift

$$(0.023 \text{ x}\_\_\_\_\_\_\_\_\_\_) + (13{,}100 \text{ x}\_\_\_\_\_) =$$

$$(\_\_\_\_\_\_\_\_\_\_\_\_\_\_)+(\_\_\_\_\_\_\_\_\_\_\_\_\_\_)=$$

$$= \$\_\_\_\_\_\_\_\_\_\_\_\_\_\_\text{/yr} \qquad \boxed{167}$$

TOTAL ANNUAL OPERATING COSTS

Fixed costs -

A. $\frac{100}{\text{Plant life, yrs*}}$ = ____________ %/yr depreciation, straight-line

B Capital = %/yr ________ %

C. Taxes, insurance, interim replacement - 4.65%

Total fixed costs = $\frac{A + B + C}{100}$ = 0.______ /yr fixed costs

(Yr fixed costs) x (total capital cost) =

(0.____________) x (________________) = $ ____________ /yr $\boxed{168}$

Sludge disposal:

Pumping to another site, off-plant

	MW		KW/MW		$/KWH**or***		hr/yr		weighed CF	
0.0016	x ________	x	1000	x	____________	x	8760	x	________	=

	MW		$/KWH** or ***		weighed CF		
14,016	x ________	x	________________	x	____________	=	$ ______________ /yr $\boxed{169}$

Truck disposal costs/14 miles:

$\frac{\text{ton dry sludge/hr}}{\text{8.47 tons dry sludge/truck hr}}$ x \$17.20 x 1.1 x 8760 x CF =

(57.25 min/trip) (\$17.20/truck hr/driver)

From Chart 4, item $\boxed{16}_A$, tons dry sludge/hr ____________________ $\boxed{16}_A$

$\boxed{16}_A$ weighed CF

____________ x 19,570 x ________________ = $ ____________ /yr $\boxed{170}$

* Plant life, years: either remaining boiler life in years from start of FGD system or 15 year life for FGD system, use lowest number of years for life.

** or *** see next page

TOTAL ANNUAL OPERATING COST

Raw Materials -

Lime

Chart 17, item $\boxed{75}$ __________ton/hr $CaCO_3$ x hr/yr x weighed CF x $/ton^a = cost/yr. $\boxed{171}$

Chart 17, item $\boxed{75}$ x hr/yr x CF x $/ton^a = cost/yr $\boxed{171}$

____________________ x 8760 x ___________ = $ _______________ $\boxed{171}$

Soda Ash:

item $\boxed{135}$ __________ton/hr

$\boxed{135}$ x cost soda ash/ton from data sheets x 8760 x C.F. = $

___________ x __________________________ x ________ x ______ = $ ____________ $\boxed{172}$

Fixation

-- ___, Chart 5, item $\boxed{16}_A$

______lb/hr dry sludge x $\frac{\text{hr/yr}}{\text{lb/ton}}$ x weighed CF x $/ton^b = cost/yr $\boxed{173}$

________________________ x 4.38 x _________ x ________ = $__________ $\boxed{173}$

Utilities:

Electrical, use appropriate

Lime-burning coal =

MW x x $/KWH* x Weighed C.F. x hr/yr = cost/yr

0.028 x_____ x 1,000 x_________ x ____________ x 8760 = $________ $\boxed{174}$

MW $/KWH C.F.

2.31×10^5 x______ x______ x______ = $_______________________/yr =
(on coal/abs. + vent.)

$_____________ $\boxed{174}$ A+V

2.08×10^5 x______ x______ x______ = $_________________________/yr =
(on coal/abs. or vent.)

$_____________ $\boxed{174}$ A

TOTAL ANNUAL OPERATING COST (Continued)

Lime--burning fuel oil =

MW $/KWH** CF

1.49 x_______x__________x_______= $________________ = $___________ 174

(on oil/abs.)

[a] If unknown use $6.32/ton

[b] If unknown use $4/ton of dry sludge

** If unknown use 0.00675/KWH based on coal at $10/ton and 12,000 BTU/lb

*** If unknown use 0.0185/KWH based on oil of $8.40/bbl and 149,000 BTU/gal.

TOTAL ANNUAL OPERATING COSTS

Summary Sheet

		Item	Cost, $
1.	Water	163	______
2.	Reheat	61	______
3.	Operating labor	164 c	______
4.	Supervision	165 c	______
5.	Maintenance	166	______
6.	Overhead	167	______
7.	Fixed costs	168	______
8,	Sludge disposal, pumping	169	______
9.	Sludge disposal, trucking	170	______
10.	Lime	171	______
11.	Soda Ash	172	______
12.	Fixation	173	______
13.	Electrical	174 A+V	______
		174 O	______
		174 A	______
	Total annual operating costs		______

Cost per kilowatt-hour:

$$\frac{\text{(total annual operating cost)}}{\text{hr/yr} \times \text{(plant rating in MW's)} \times 1{,}000 \times \text{(weighed capacity factor)}} =$$

$$\frac{(\underline{\hspace{6cm}})}{8760 \times (\qquad\qquad) \times 1{,}000 \times (\qquad)} = \$\underline{\hspace{4cm}}\text{/KWH}$$

APPENDIX D

MAGNESIUM OXIDE SCRUBBING

NOTE: For purposes of clarity and continuity, Tables and Charts have been numbered sequentially in this report with no differentiation between Tables and Charts.

INFORMATION REQUIRED

Boiler No.						
Type of furnace						
MW at maximum continuous						
Age of unit , years						
Life, years remaining						
Capacity factor, yr._____						
Maximum continuous fuel, ton/hr or gal./min						
Maximum continuous, MM BTU/hr						
acfm at____°F						
Fly ash/total ash, %						
Efficiency of existing particulate control,%						

Cost of electricity/KW (Plant) =$________ . Cost of water/M gal. (Plant) = $______________

Coal, cost/ton $__________

% sulfur by weight __________

% ash by weight __________

HHV, BTU/lb __________

Oil, cost/bbl $__________

% sulfur by weight __________

BTU/gal __________

Specific Gravity __________

SO_2 permissible __________ lb SO_2/MM BTU } State or Federal regulations

Fly ash permissible__________ lb fly ash/MM BTU }

INFORMATION REQUIRED (continued)

Estimated land cost per acre (current) $______________

Possible interference determining the location of flue gas desulferization (FGD) system:

Congestion between stack and plant ☐ Yes ☐ No

Congestion between stack and/or plant with property line, coal pile, etc., ☐ Yes ☐ No

Identify problem areas and location: ______________________________

Terrain ______________________________

Conduits ______________________________

Possible obstructions ______________________________

Source of MgO available ______________________________

and % purity ________

SO_2 EMISSION DETERMINATION

To determine the SO_2 emissions (lb/MM BTU) in the flue gas, Chart 1:

Enter % sulfur by weight of fuel (oil or coal) on $\boxed{1}$

Enter heating value of fuel (BTU/lb) on $\boxed{2}$

Connect $\boxed{1}$ and $\boxed{2}$ and extend to $\boxed{3}$ and read and record:

SO_2 emissions (lb/MM BTU) in flue gas ____________ $\boxed{3}$

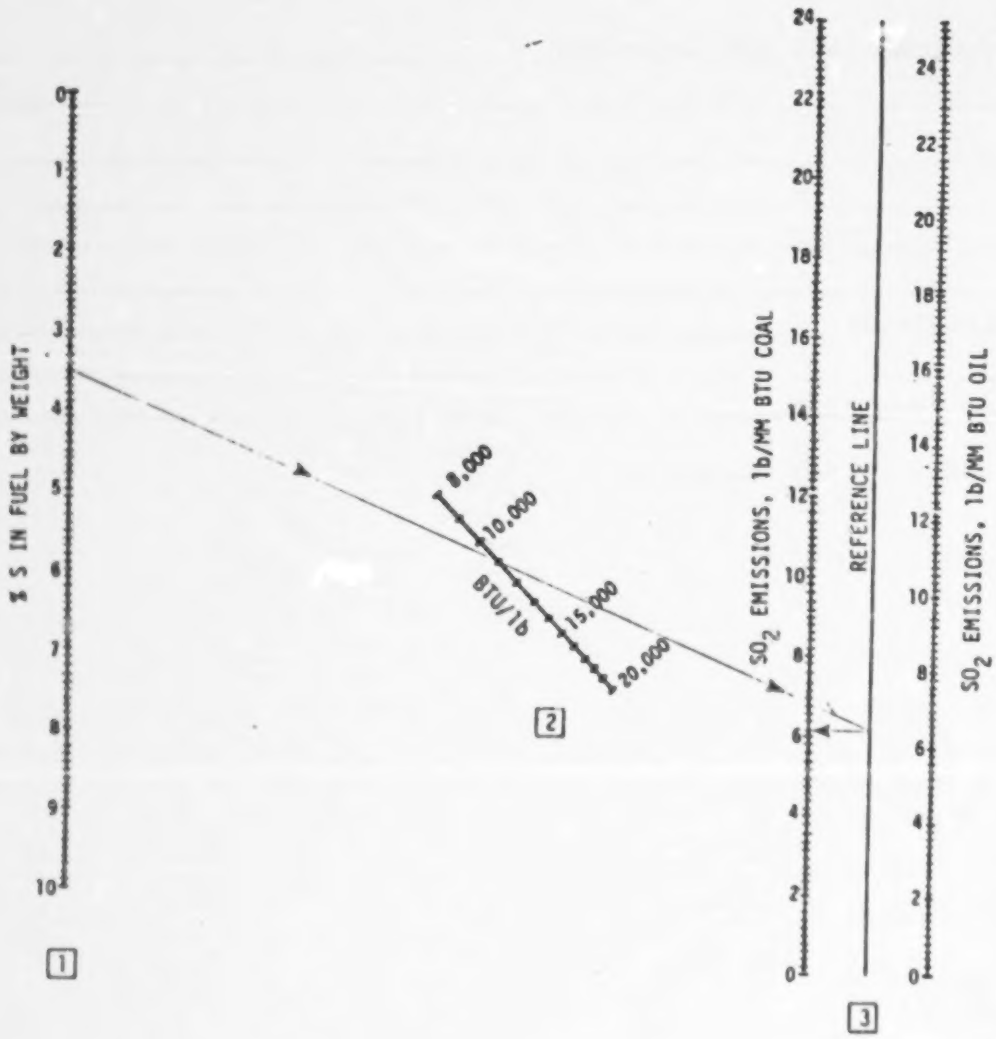


Chart 1. SO_2 EMISSION DETERMINATION

Assumptions:

(1) 9[illegible] of sulfur in coal converted to SO_2
(2) 100% of sulfur in oil converted to SO_2

SO_2 REMOVAL REQUIREMENTS

To calculate SO_2 emissions (lb/MM BTU) to be removed:

Enter from page D-4, Chart 1, item $\boxed{3}$ the lb/MM BTU __________ $\boxed{3}$

Enter from the data sheet, allowable SO_2 emissions (lb/MM BTU) from the State or federal regulations __________ $\boxed{4}$

Subtract $\boxed{4}$ from $\boxed{3}$ to calculate SO_2 emissions (lb/MM BTU) to be removed __________ $\boxed{5}$

MAGNESIUM OXIDE REQUIREMENTS

To determine the MgO requirements (lb/hr) Chart 2:

Enter the SO_2 emissions (lb/MM Btu) to be removed on item $\boxed{6}$ from page D-5, item $\boxed{5}$; record __________ $\boxed{6}$

Enter stoichiometric requirements for MgO on item $\boxed{7}$ *

Connect $\boxed{6}$ and $\boxed{7}$ and extend to $\boxed{8}$ and read and record:

MgO requirements (lb/MM Btu) __________________ $\boxed{8}$

Record from the data sheets the heat input (MM Btu/hr)____ $\boxed{9}$

Multiply $\boxed{8}$ by $\boxed{9}$ and record:

MgO requirements (lb/hr) ____________ $\boxed{10}$

* If unknown, use 1.05

Multiply $\boxed{6}$ by $\boxed{9}$ and record: lb SO_2/hr removed

____________ $\boxed{12}$

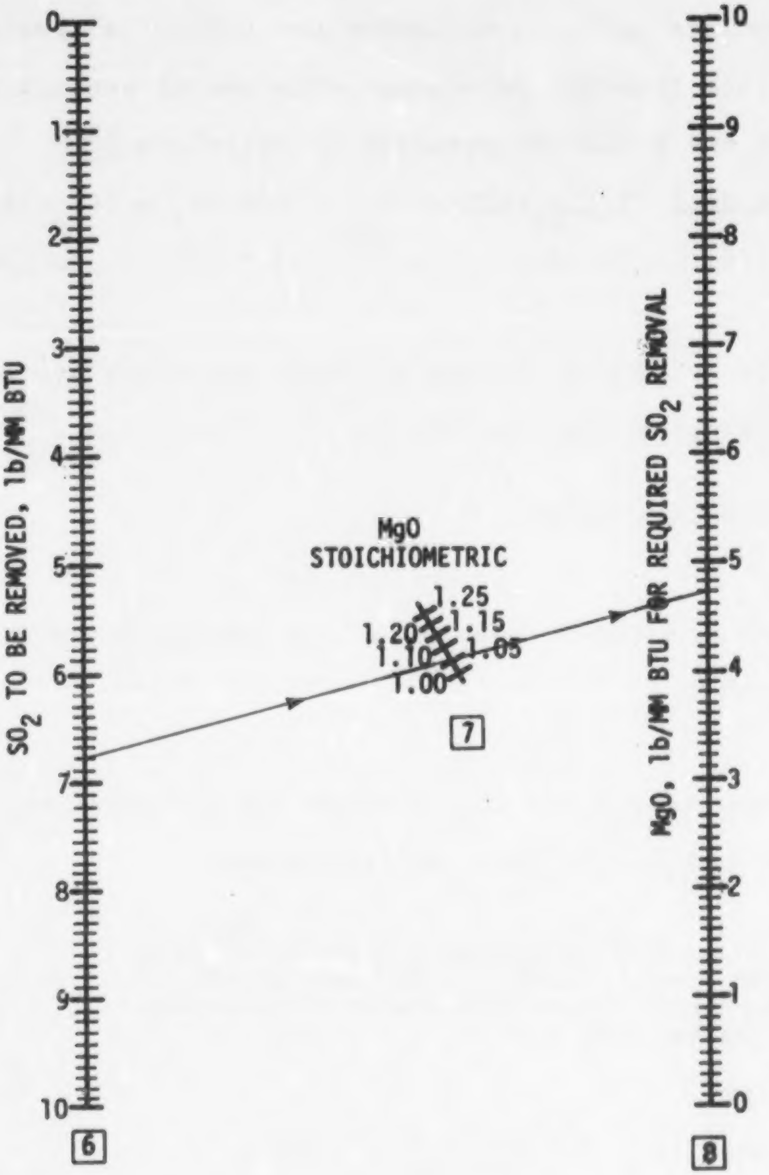


Chart 2. MgO REQUIREMENTS - lb/hr.

FLY ASH EMISSION RATE CALCULATIONS FOR VENTURI DETERMINATION

To calculate fly ash emitted:

If the fly ash emitted (lb/MM BTU) in $\boxed{13}$ after passing through an existing particulate emission collector per boiler is greater than the allowable rate from the data sheet, the use of venturi is necessary. Use the following equation to calculate $\boxed{13}$

$$\boxed{13} = \left[\left(\frac{\text{\% ash in coal}}{100}\right)\left(\frac{\text{\% fly ash*}}{100}\right)\left(1-\frac{\eta_c}{100}\right) \div \text{BTU/lb}\right] \times 10^6 = \text{lb/MM BTU}$$

$$= \left[0.\_\_\_\_\_\_)(0.\_\_\_\_\_\_)\ (1-0.\_\_\_) \div \_\_\_\_\_\_\_\_\right] \times 10^6 \ = \_\_\_\_\_\_ \text{lb/MM BTU}$$

where

η_c = Efficiency of particulate emission collector system

BTU/lb = Heat value of fuel (MM BTU/lb)

% ash = from the data sheet

If fly ash removal is required for any or all of the units VENTURI COST CALCULATIONS will be used.

*If the percent of fly ash to ash is not known use the appropriate tabulated values for the boiler under consideration.

Type boiler - coal-fired	fly ash to ash, %
General pulverized	80
Dry bottom	85
Wet bottom	65
Cyclone	10

SLUDGE GENERATED

To determine the dry sludge (lb/hr) generated, Chart 3:

From page D-8 , item $\boxed{13}$ enter calculation of fly ash (lb/MM BTU) $\boxed{13}$

From data sheet, heat input maximum continuous rating, record here as (MM BTU/hr) ______________ $\boxed{14}$

Dry Sludge = $\boxed{13}$ x $\boxed{14}$ = $\boxed{15}$ lb/hr

= ______ x ______ = _______ lb/hr $\boxed{15}$

$\boxed{15}$

______ ÷ 2000 = _______ ton/hr $\boxed{15}_A$

Enter $\boxed{15}$ on $\boxed{16}$, Chart 3, enter _____%* by weight dry sludge on $\boxed{17}$

Connect $\boxed{16}$ and $\boxed{17}$ and extend to $\boxed{18}$ and read:

Wet Sludge (lb/hr) = _________ $\boxed{18}$

Water returned from pond, lb/hr = $\boxed{19}$

$\boxed{18}$ $\boxed{16}$

________ - _____________ = ______________ lb/hr $\boxed{19}$

*if unknown use 10%

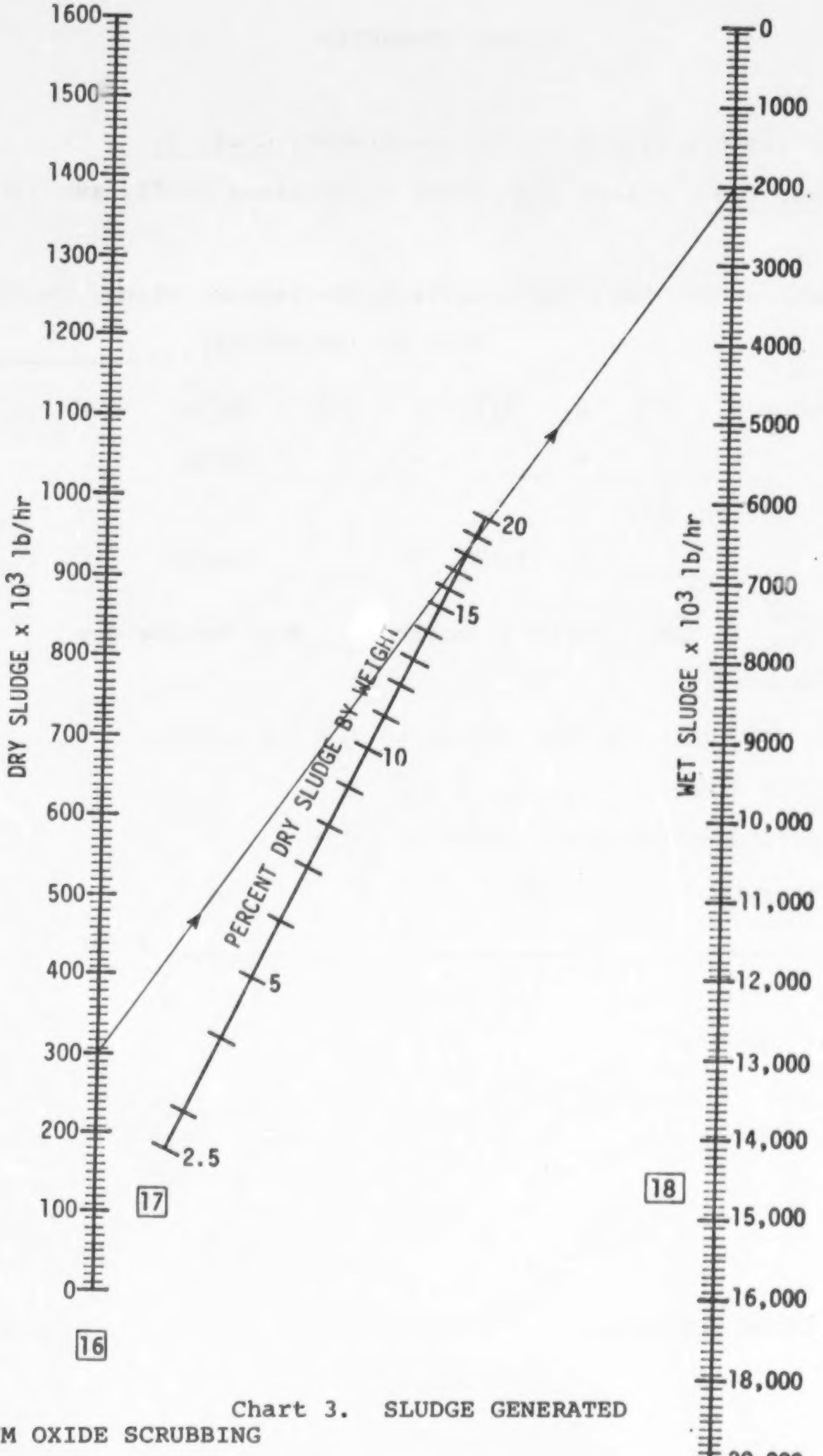


Chart 3. SLUDGE GENERATED

VENTURI AND ABSORBER COSTS

To determine the costs of venturi and absorber (including demister) using lime, Chart 4:

First, determine number of scrubber trains -

Enter acfm at °F of flue gas from the data sheet on $\boxed{20}$, either per boiler or combined plant total if °F is the same for all boilers.

Enter temperature of flue gas (°F) on $\boxed{21}$

Connect $\boxed{20}$ and $\boxed{21}$ and extend to $\boxed{22}$ and read flue gas acfm at 125°C (saturated) and enter________acfm at 125°F and sat. $\boxed{22}$

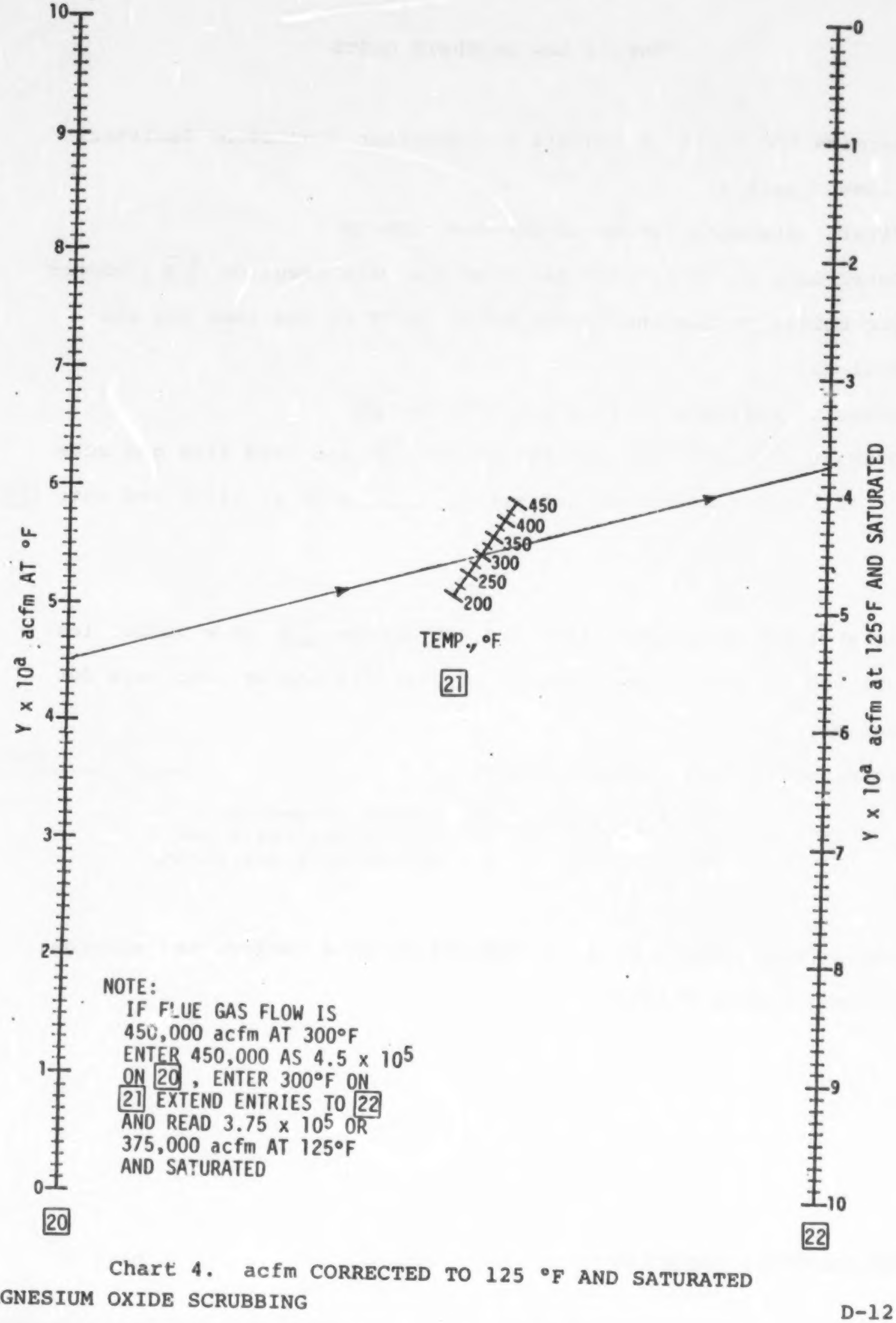
If acfm at 125°F is greater than 375,000 divide $\boxed{22}$ by a number less than 375,000 to give a whole number of venturis and/or absorbers for each boiler.

acfm per venturi and/or absorber ____________ $\boxed{23}$

$$\frac{\_\_\_\_\_\_\_\_\boxed{22}}{\boxed{23}} = \_\_\_\_\_\_\_\_\boxed{24}$$

number of venturis and/or absorbers per boiler or power plant.

A venturi, or an absorber, or a combination of a venturi and absorber is sometimes called a train.



NOTE:
IF FLUE GAS FLOW IS
450,000 acfm AT 300°F
ENTER 450,000 AS 4.5×10^5
ON 20, ENTER 300°F ON
21 EXTEND ENTRIES TO 22
AND READ 3.75×10^5 OR
375,000 acfm AT 125°F
AND SATURATED

Chart 4. acfm CORRECTED TO 125 °F AND SATURATED

VENTURI AND ABSORBER COSTS

Then determine absorber costs (no venturi required) Chart 5:

Enter item $\boxed{22}$ from page D-12 Chart 4 on Chart 5 on $\boxed{25}$

Enter for the absorber the cost factor of 1.1 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read absorber cost

$ ______________ $\boxed{27}_{A}$

Or determine venturi and absorber costs (if a venturi is required)

Enter item $\boxed{22}$ from page D-12 Chart 4 on Chart 5 on $\boxed{25}$

Enter for venturi the cost factor of 2.0 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read venturi and absorber costs $ ______________ $\boxed{27}_{V + A}$

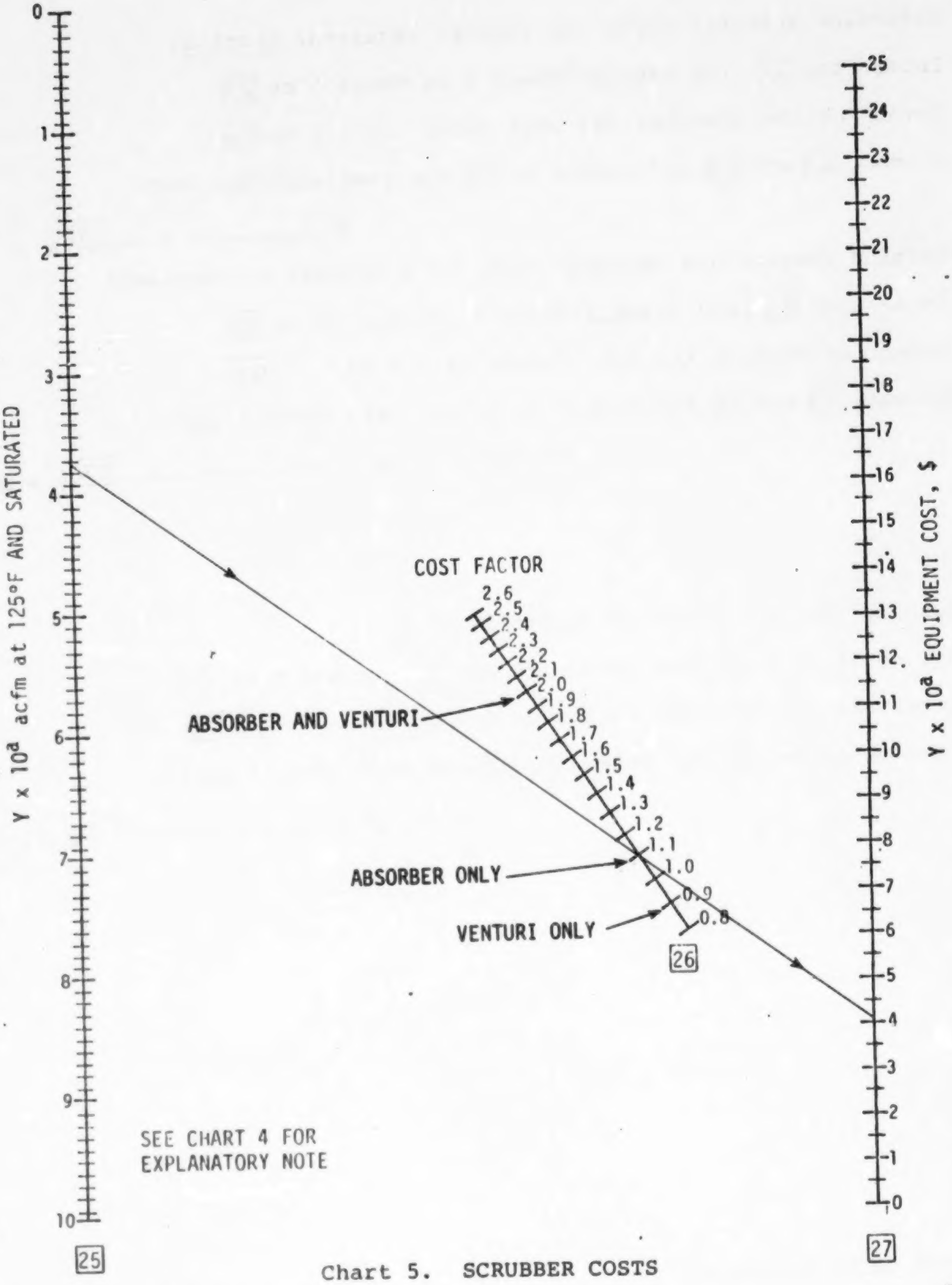
Or determine venturi costs (no absorber):

Now enter item $\boxed{22}$ from page D-12 Chart 4 on Chart 5 on $\boxed{25}$

Enter the venturi cost factor of 0.9 on $\boxed{26}$

Connect $\boxed{25}$ and $\boxed{26}$ and extend to $\boxed{27}$ and read venturi costs

$ ______________ $\boxed{27}_{V}$



SEE CHART 4 FOR EXPLANATORY NOTE

Chart 5. SCRUBBER COSTS

HOLDING TANK CAPACITY

To determine the holding tank capacity for absorber and/or venturi

Chart 6:

Enter flue gas acfm from page D-11, item $\boxed{23}$ on Chart 6, item $\boxed{29}$

Enter L/G* (liquid flow rate, gpm/1000 acfm at 125°F) on $\boxed{30}$

Connect $\boxed{29}$ and $\boxed{30}$ and extend to $\boxed{31}$, read and record:

Liquid flow rate (gal/min) $\boxed{31}_A$ for absorber

Liquid flow rate (gal/min) $\boxed{31}_V$ for venturi

Enter retention time on $\boxed{32}$ **

Connect $\boxed{31}$ and $\boxed{32}$ and extend to $\boxed{33}$, read and record:

Tank capacity (gal) per absorber $\boxed{33}_A$

(gal) per venturi $\boxed{33}_V$

*If unknown use L/G = $\boxed{40}$ for absorber and L/G = $\boxed{15}$ for venturi

**If unknown, use 10 minutes for absorber and 4 minutes for venturi.

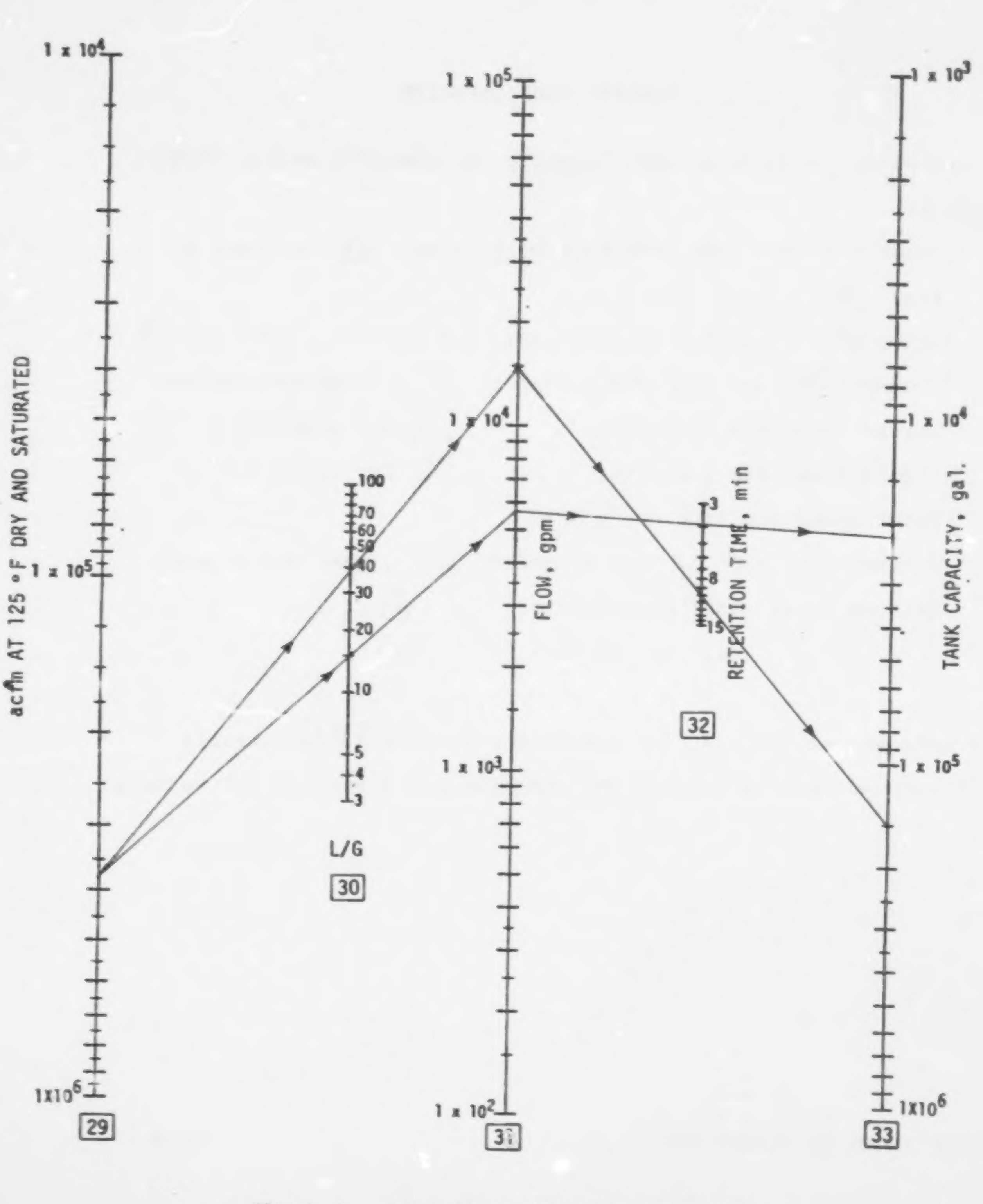


Chart 6. FLOW RATE AND TANK CAPACITY

HOLDING TANK AGITATOR COSTS

To determine the cost of agitators per tank, Table 7:

Compare tank capacity (gallons) from page D-16, Chart 6, item $\boxed{33}_A$ and/or $\boxed{33}_V$ on Chart 7 under tank capacity in gallons column and record:

Cost of agitators per tank - absorber $\$$______________ $\boxed{34}_A$

venturi $\$$______________ $\boxed{34}_V$

Total cost of venturi and/or absorber:

($\boxed{34}_A$ + $\boxed{34}_V$) x No. of venturi or absorbers from item $\boxed{24}$

(________+________) x ________________ = $\$$____________ $\boxed{35}$

Table 7. AGITATOR COST

Tank capacity, gal.	Agitators No.	Agitators $\boxed{34}_A$ or $\boxed{34}_V$, cost, $\$$
0 to 34,000	1	2,000
34,000 to 67,000	2	4,000
67,000 to 101,000	3	6,000
101,000 to 135,000	4	8,000
135,000 to 162,000	5	10,000
162,000 to 188,000	6	12,000
188,000 to 220,000	7	14,000
220,000 to 251,000	8	16,000
251,000 to 283,000	9	18,000

TABULATE THE COST OF TANK, PUMP AND AGITATOR AS BELOW, IF VENTURI IS REQUIRED,

PREPARE SEPARATE TABLES FOR VENTURI AND ABSORBER. PLANT TOTALS

$\boxed{39}_T$, $\boxed{49}_T$, AND $\boxed{35}_T$ SHOULD INCLUDE ABSORBER AND VENTURI EQUIPMENT.

Boiler No.	Flue gas rate, acfm	Flue gas temp, F.	Flue gas a 125° F, acfm	No. of trains	Flue gas rate @125°F per train	Tank cost per train, $	Tank cost per boiler, $	Pump cost per train, $	Pump cost per boiler, $	Agitator cost per train, $	Agitator cost per train, $
Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ	Ⓕ	Ⓖ	Ⓖ x Ⓔ	Ⓗ	Ⓗ x Ⓔ	Ⓙ	Ⓙ x Ⓔ
					Total/plant						
							$\boxed{39}_T$		$\boxed{49}_T$		$\boxed{35}_T$

HOLDING TANK COSTS

To determine the tank cost the values in the chart are based on using \$12.50/ft^2 for a field-fabricated, rubber-lined tank, Chart 8:

Enter tank capacity (gallons) on $\boxed{36}$ from page D-16, Chart 6, items $\boxed{33}_A$ and $\boxed{33}_V$, move vertically to $\boxed{37}$

From $\boxed{37}$ move horizontally to $\boxed{38}$, read and record:

Tank cost per absorber \$________________ $\boxed{38}_A$

Cost per venturi \$________________ $\boxed{38}_V$

Total Cost:

($\boxed{38}_A$ + $\boxed{38}_V$)x No. of absorbers $\boxed{24}$ = cost of holding tanks $\boxed{39}$

(_________+___________)x_____________ = \$______________________ $\boxed{39}$

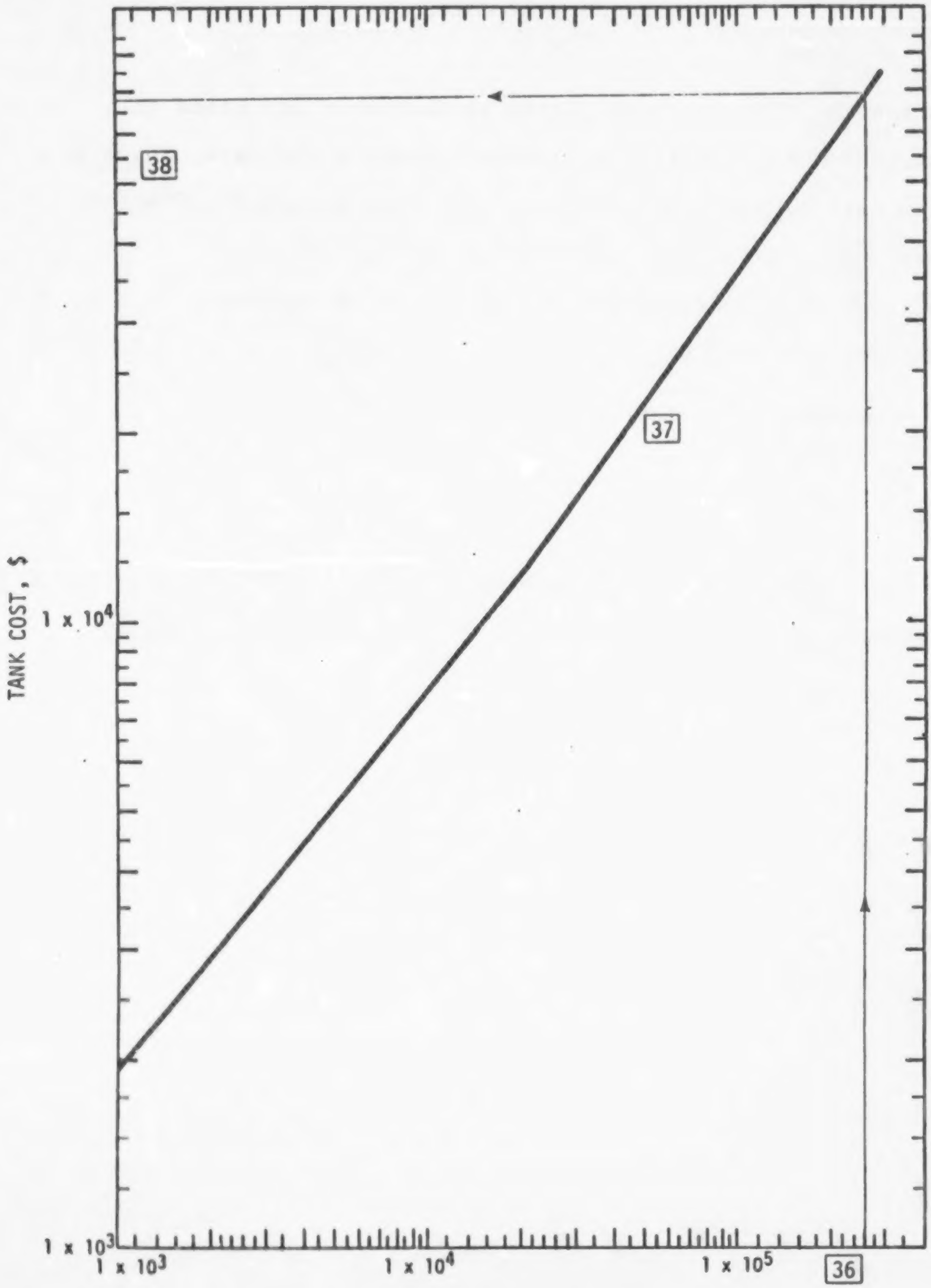


Chart 8. HOLDING TANK COSTS

HOLDING TANK PUMP COSTS

To determine the total pump cost for absorbers and/or venturi, Chart 9:

Enter gpm on $\boxed{40}$ from page D-16 Chart 6, item $\boxed{31}_A$ for the absorber and $\boxed{31}_V$ for the venturi. Select minimum number of pumps on $\boxed{41}$ (note 10,000 gpm* per pump is maximum), use minimum number of pumps per train and add 1 spare pump per tank.

Connect $\boxed{40}$ and $\boxed{41}$ and extend to $\boxed{42}$, read and record:

Flow rate (gpm) per pump $\underline{\qquad\qquad}$ absorber; $\underline{\qquad\qquad}$ venturi

Tabulate:	No. of pumps $\boxed{41}$	gpm/pump $\boxed{42}$	No. of trains $\boxed{24}$
Absorber			
Venturi			

For total pump cost for venturi and/or absorber

Enter $\boxed{41}_A$, $\boxed{41}_V$ on $\boxed{43}_A$, $\boxed{43}_V$

Connect $\boxed{42}$ and $\boxed{43}_A$ and extend to $\boxed{44}$, read and record:

Connect $\boxed{42}$ and $\boxed{43}_V$ and extend to $\boxed{44}$, read and record:

Variable cost per pump $\$\underset{\boxed{44}_A}{\underline{\qquad\qquad}}$ absorber; $\$\underset{\boxed{44}_V}{\underline{\qquad\qquad}}$ venturi

* If gpm per pump is less than or 5,000 gpm calculate cost as follows:

record gpm from page D-16 Chart 6 item $\boxed{31}_A$ for the absorber $\underline{\qquad\qquad}\boxed{45}$

and item $\boxed{31}_V$ for the venturi $\underline{\qquad\qquad}\boxed{46}$

number of trains from page D-11 item $\boxed{24}$ $\underline{\qquad\qquad}$

number of pumps per train 1 + 1 spare

absorber pump costs: $2 \text{ x } .79 \text{ x } (\boxed{45}) \text{ x } (\boxed{24}) = \$\ \boxed{47}_A$

$1.58 \text{ x } (\underline{\qquad}) \text{ x } (\underline{\qquad}) = \$\underline{\qquad\qquad}\boxed{47}_A$

$1.84 \text{ X } (\boxed{46}) \text{ x } (\boxed{24}) = \$\ \boxed{47}_V$

$1.84 \text{ x } (\underline{\qquad}) \text{ x } (\underline{\qquad}) = \$\underline{\qquad\qquad}\boxed{47}_V$

HOLDING TANK PUMP COSTS (Continued).

Pump costs, total: from calculations [(1 gpm to 5,000 gpm per pump)]

$\boxed{47}_V$ + $\boxed{47}_A$ = $\boxed{49}$

________________ + __________________ = $________________ $\boxed{49}$

Pump costs, total: from Chart 9 [(5,001 gpm to 10,000 gpm per pump)]

$\boxed{48}_V$ + $\boxed{48}_A$ = $\boxed{49}$

________________ + __________________ = $________________ $\boxed{49}$

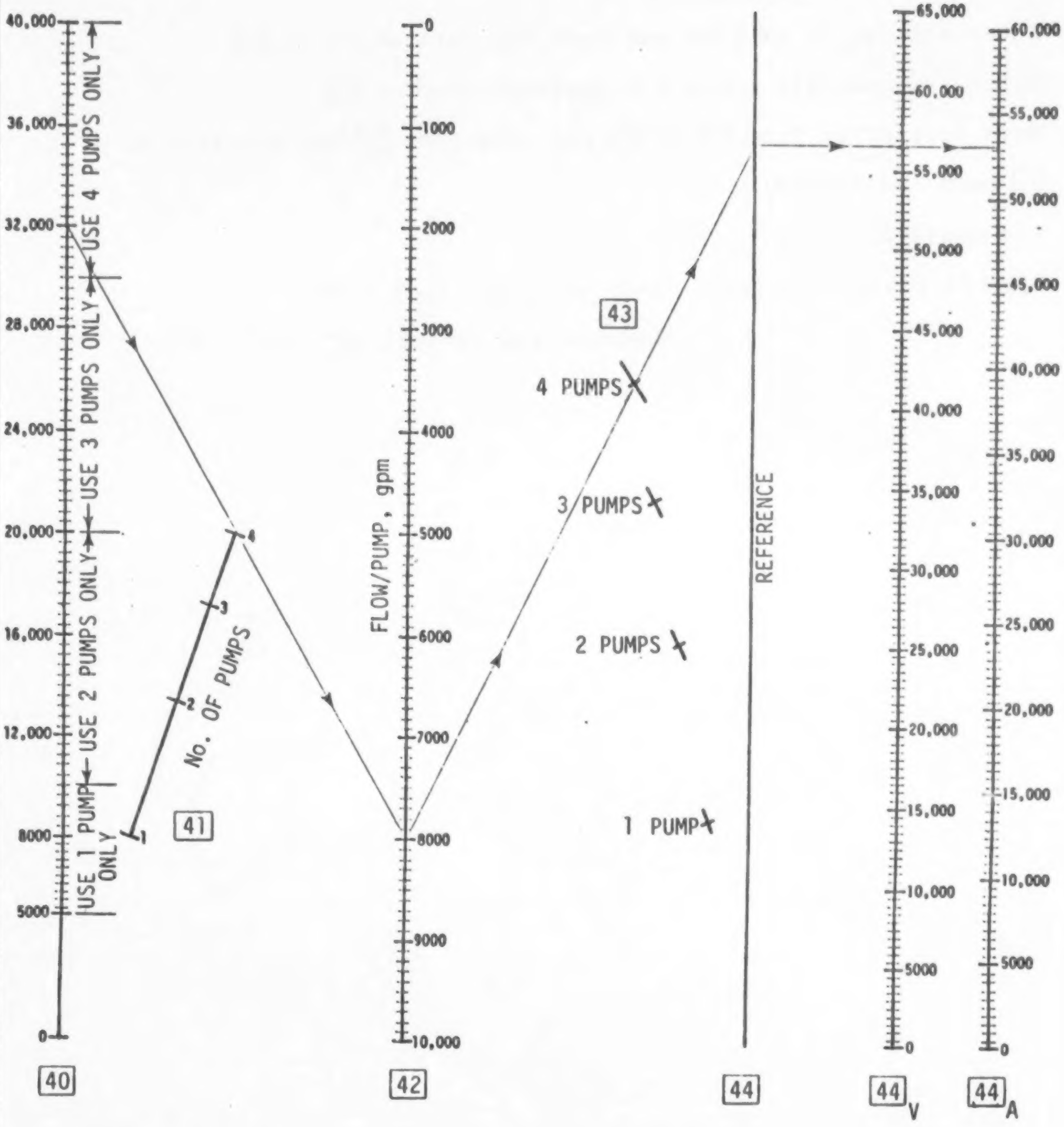


Chart 9. HOLDING TANK VARIABLE PUMP COSTS

FAN COSTS

To determine fan costs, Chart 10:

Enter acfm at °F of flue gas from the data sheet on $\boxed{50}$

Select appropriate curve for pressure drop* on $\boxed{51}$

Move vertically from $\boxed{50}$ to $\boxed{51}$ and then from $\boxed{51}$ horizontally to $\boxed{52}$ read and record:

Fan costs $____________ $\boxed{52}$

*Typical pressure drops: Absorber 19" (16" + 3");

Absorber and venturi 28" (25" + 3")

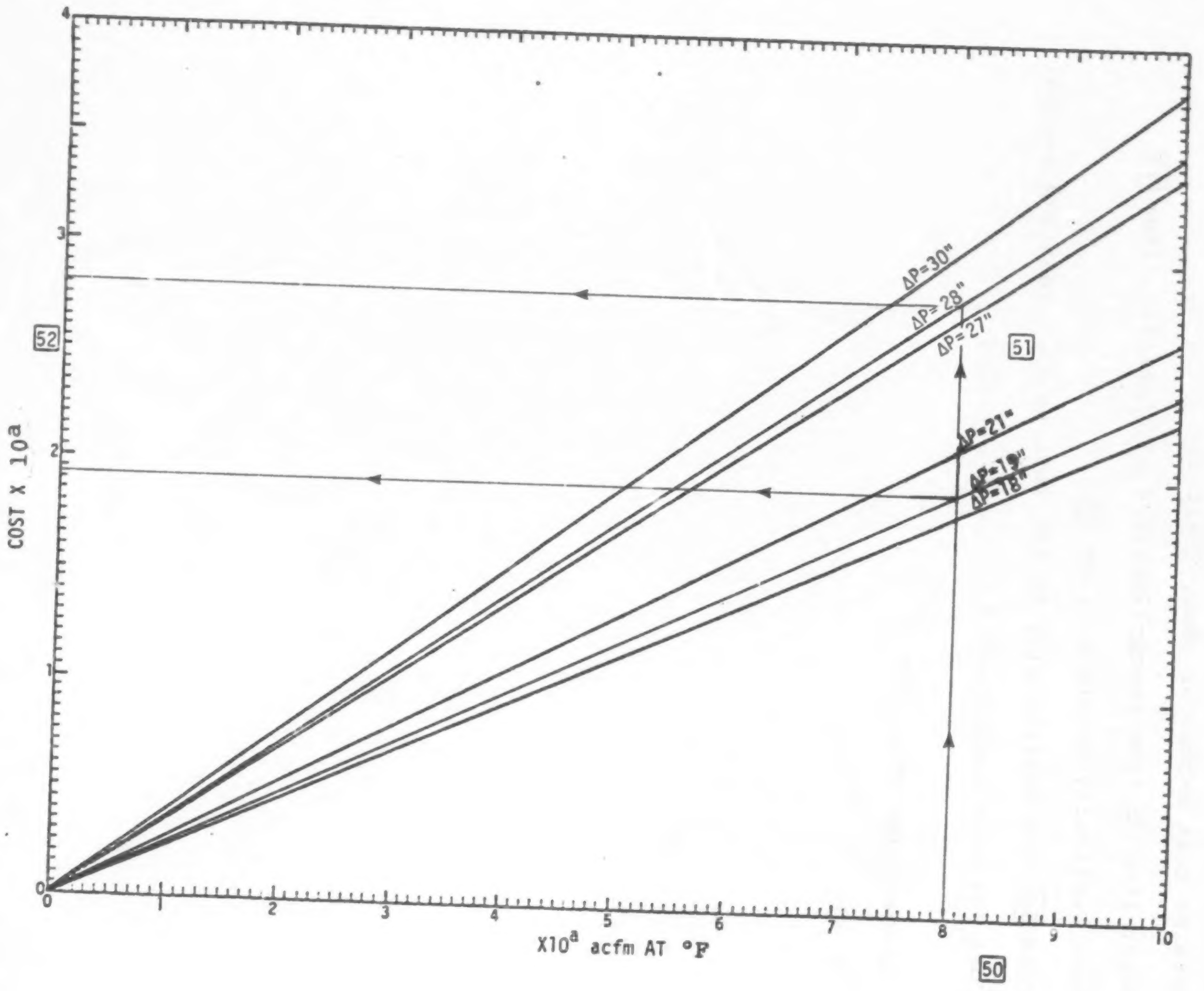


Chart 10. FAN COST

HEAT EXCHANGER COST

To determine heat exchanger cost, Chart 11:

Enter item $\boxed{22}$ from page D-12 Chart 4 on Chart 11 , item $\boxed{53}$

Move vertically upward to item $\boxed{54}$

From $\boxed{54}$ move horizontally to the left to $\boxed{55}$, read and record:

Cost for heat exchangers $_______________ $\boxed{55}$

*If unknown, use ΔT = 50°F

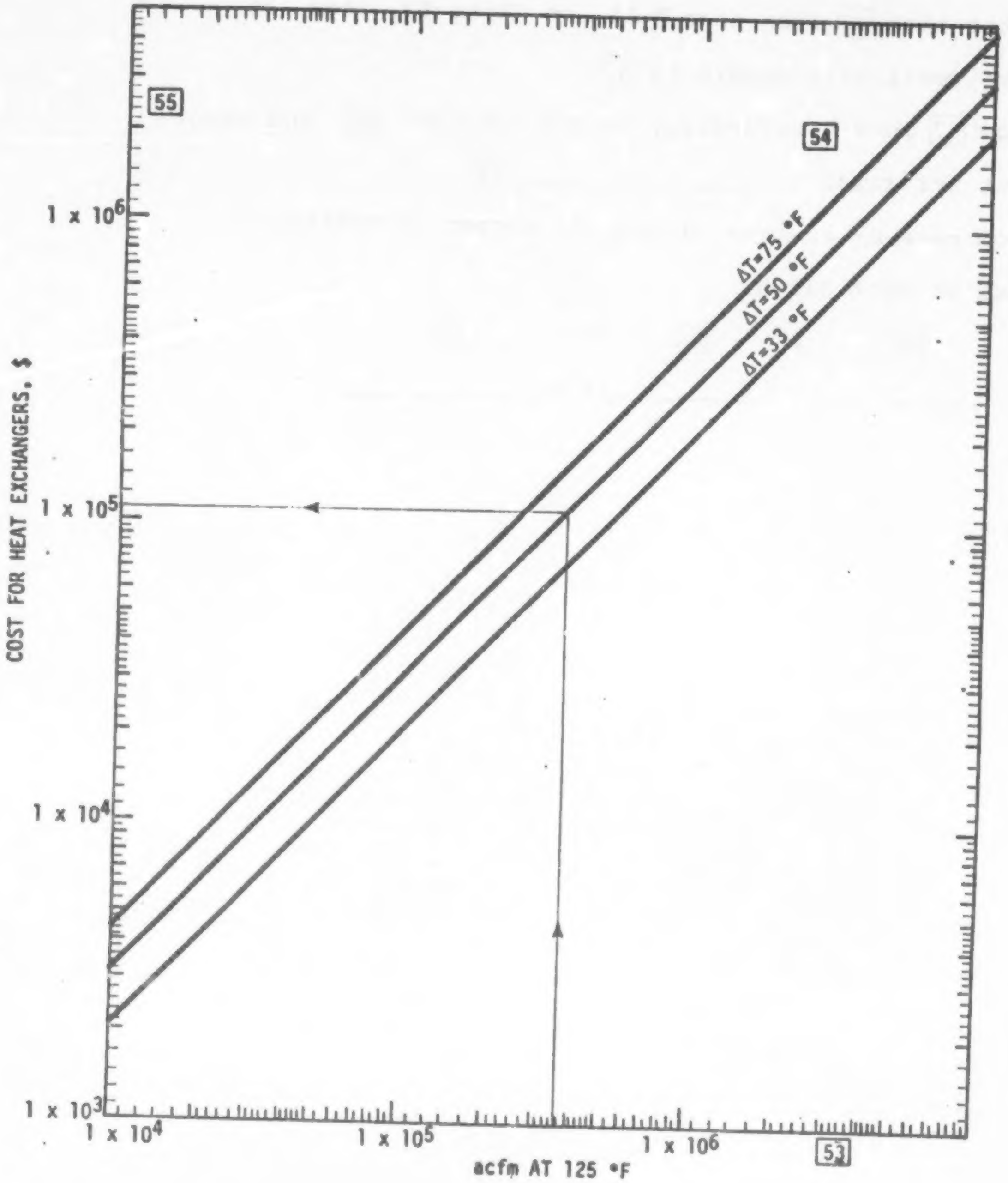


Chart 11. HEAT EXCHANGER COSTS

SOOT BLOWER COST

To determine soot blower cost, Chart 12:

Enter item $\boxed{23}$ from page D-11, on Chart 12, item 56

Move vertically upward to $\boxed{57}$

From $\boxed{57}$ move horizontally to the left to $\boxed{58}$ and read:

Cost per train $______________ $\boxed{58}$

From page D-11, item 24 record, number of trains

Cost of soot blower

$\boxed{58}$ x $\boxed{24}$ = $\boxed{59}$

$___________ x ___________ = $ ___________

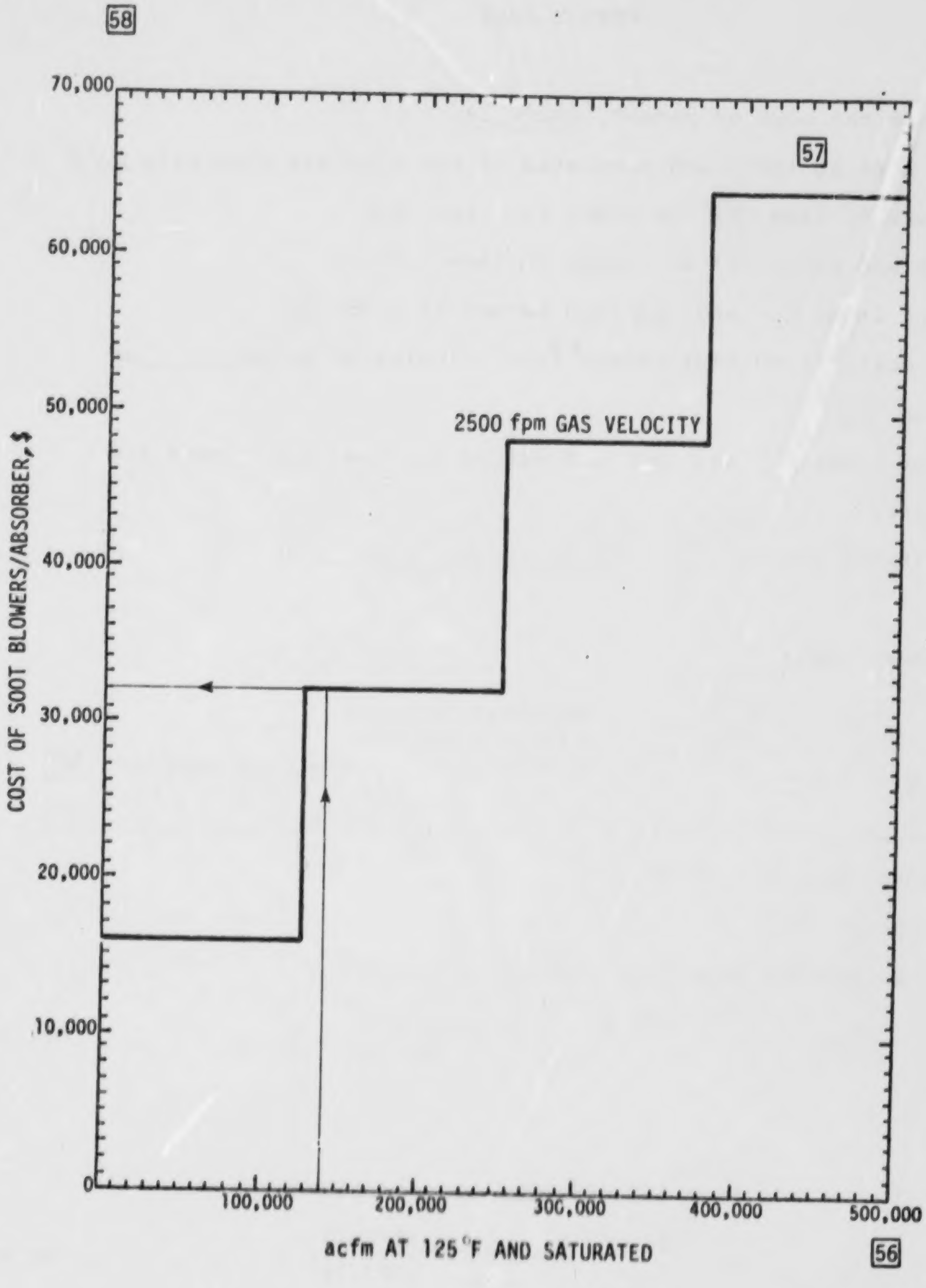


Chart 12. SOOT BLOWER COST

REHEAT COST

To calculate the cost of reheat, Chart 13:

Enter acfm at 125°F and saturated of the flue gas from page D-12 Chart 4, item $\boxed{22}$ on Chart 13, item $\boxed{60}$

Select and enter ΔT* of reheat on item 61 ,

Connect items $\boxed{60}$ and $\boxed{61}$ and extend to item $\boxed{62}$

Enter costs ($/MM BTU) reheat** from calculation below_______on item $\boxed{63}$

Connect items $\boxed{62}$ and $\boxed{63}$ and extend to item $\boxed{64}$, read and record:

Cost ($/hr) reheat ____________________ $\boxed{64}$

Annual reheat cost:

$\boxed{64}$ Weighted capacity factor from data sheet, = reheat cost/yr $\boxed{65}$

$________________ x 8760 hr/yr x 0.______________ = $ ________________ $\boxed{65}$

*If unknown, use ΔT = 50°F

**Reheat Cost -

Coal: To correct from 12,000 BTU/lb and $10/ton

$$=665 \times \frac{\underline{\qquad\qquad}\,(\$/\text{ton})}{\underline{\qquad\qquad}\ \text{BTU/lb.}} = \$\underline{\qquad\qquad\qquad}/\text{MM BTU}$$

Oil: To correct from 149,000 BTU/gal. and $10/bbl

$$=31{,}707 \times \frac{\underline{\qquad\qquad}\,(\$/\text{bbl})}{\underline{\qquad\qquad}\ \text{BTU/lb}} = \$\underline{\qquad\qquad\qquad}/\text{MM BTU}$$

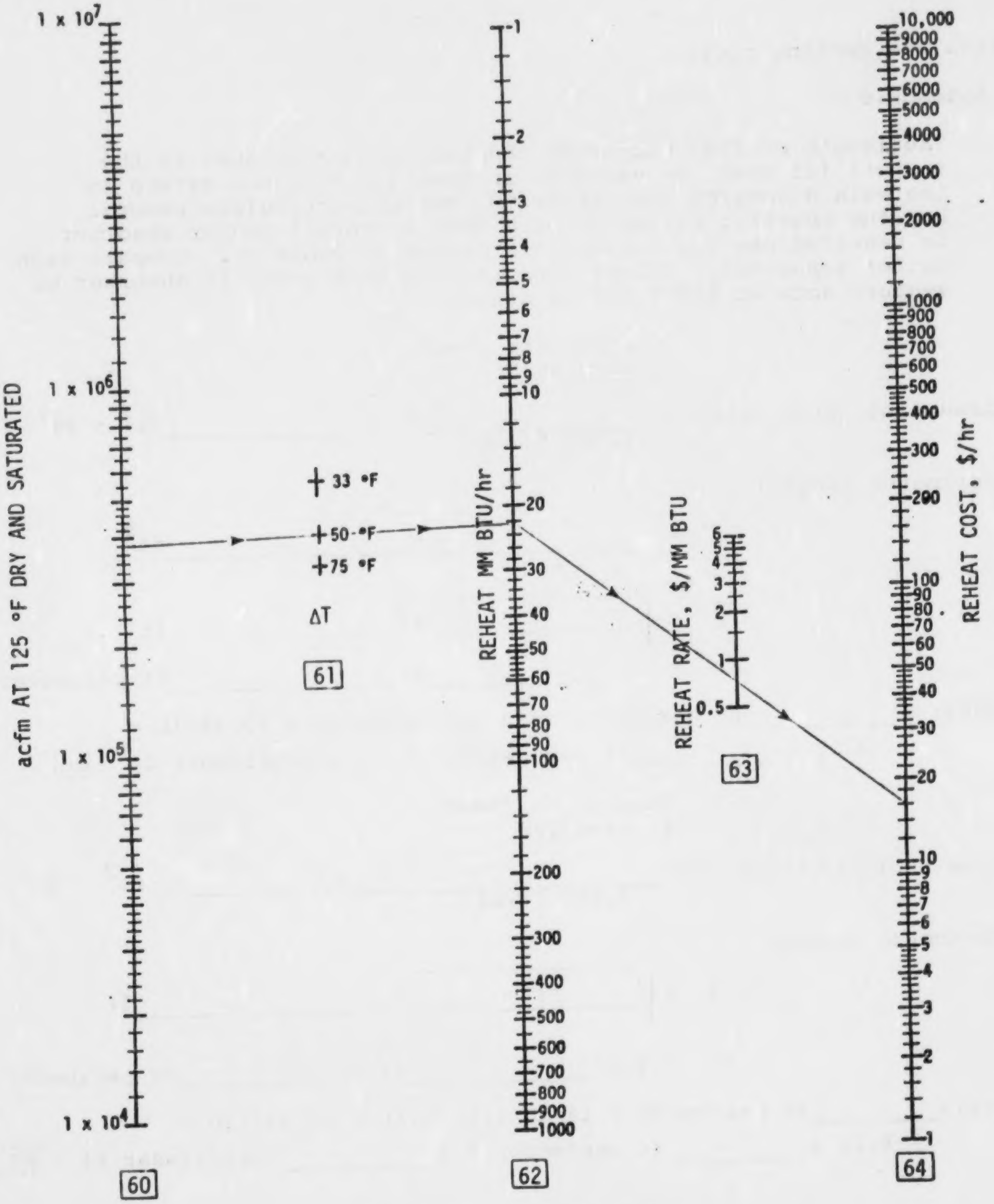


Chart 13. REHEAT COSTS

DUCT COSTS

To calculate ducting cost:

Assumption-

The length of flue duct from the main discharge duct to the venturi (if used) is variable in feet and also the return to the main discharge duct after SO_2 and/or particulate removal. For the specific boiler if more than 1 venturi and/or absorber is required use the multipliers listed in Table 14. Compute each boiler separately, unless identical to each other in absorber or venturi acfm at 125°F and saturated.

From data sheet,
acfm at °F

Area duct (from main) in: $\dfrac{\rule{4cm}{0.4pt}}{3{,}500\ \text{ft/min}} = \rule{4cm}{0.4pt}\ \text{ft}^2 = 2x^2$

Perimeter length:

$$\lambda^2 = \frac{\rule{4cm}{0.4pt}}{2} = \rule{4cm}{0.4pt}\ \text{ft}^2$$

$$\lambda = \sqrt{\frac{\rule{3.5cm}{0.4pt}}{2}\ \text{ft}^2} = \rule{3.5cm}{0.4pt}\ \text{ft}$$

$$6\lambda = 6\times \rule{3.5cm}{0.4pt}\ \text{ft} = \rule{3.5cm}{0.4pt}\ \text{ft perimeter}$$

Cost: ______________ ft perimeter x 18 lb/linear ft x $0.39/lb =

7.02 x ___________ ft perimeter = $_____ cost/linear ft $\boxed{66}$

Page D-12, Chart
4, item $\boxed{22}$

Area duct (to main) out: $\dfrac{\rule{5cm}{0.4pt}}{2{,}500\ \text{ft/min}} = \rule{3cm}{0.4pt}\ \text{ft}^2 = 2x^2$

Perimeter length:

$$\lambda = \sqrt{\frac{\rule{1.5cm}{0.4pt}\ \text{ft}^2}{2}} = \rule{4.5cm}{0.4pt}\ \text{ft}$$

$$6\lambda = 6\times \rule{3.5cm}{0.4pt}\ \text{ft} = \rule{3cm}{0.4pt}\ \text{ft perimeter}$$

Cost: _________ ft perimeter x 18 lb/linear ft x $0.445/lb =

8.01 x _________ ft perimeter = $___________ cost/linear ft $\boxed{67}$

DUCT COST

Table 14. MULTIPLIER FOR DUCT COST

No. of absorbers and/or venturis per boiler	Venturi and absorber in	Venturi or absorber only in	Venturi plus absorber out	Venturi or absorber only out
1	110	70	70	50
2	190	114	113	93
3	250	180	143	123
4	305	225	175	155
5	356	266	205	183
6	410	310	235	208
7	453	346	262	242
8	490	378	288	268
9	535	415	315	295
10	579	452	343	324

Duct cost in -

(in) cost/linear ft × (Table 14 multiplier + Estimated ft to main duct*-30') = Duct cost (in) $\boxed{68}$

$\boxed{66}$ __________ × (__________ + __________ -30') = __________ $\boxed{68}$

Duct cost out -

(out) cost/linear ft × (Table 14 multiplier + Estimated distance to main duct**-50') = Duct cost (out) $\boxed{69}$

$\boxed{67}$ __________ × (__________ + __________ -50') = __________ $\boxed{69}$

Total duct cost -

$\boxed{68}$ duct cost (in) + $\boxed{69}$ duct cost (out) = $\boxed{70}$ total duct cost

$ __________ + $ __________ = $ __________ $\boxed{70}$

* If congested area add 230 ft for estimated ft.

** If congested area add 200 ft for estimated ft.

FLUE GAS SHUTOFF AND BYPASS VALVES

To calculate flue gas shutoff and bypass valve costs:

Assumption-

Based on 4 vanes/axis in short dimension based on height of 20 ft and width of 10 ft,
Stainless steel at \$141.6/ft^2; carbon steel at \$99.1/ft^2 ; fabricated

Flue gas valve (in) at main duct to create a bypass

$$\frac{\text{From the data sheet acfm at } \underline{\qquad}{}^\circ\text{F}}{3{,}500} \Big/ \text{Boiler} = \underline{\qquad\qquad}\ \text{ft}^2 = 2w^2$$

$$W = \sqrt{\frac{\underline{\qquad\qquad}}{2}}\ \text{ft}^2;\ W \times 2 = \underline{\qquad} \times 2 = \text{height, ft, H.}$$

$$\text{Valve cost A} = (1.5 \times H)\ [(99.1) \pm^{*} (3.1)\ (H-20)\ (0.5H-10)]$$

*H greater than 20 ft, sign is +, less than 20 ft sign is -.

$$= (1.5 \times \overset{H}{\underline{\qquad}})\ [(99.1) \pm (3.1)\ (\overset{H}{\underline{\quad}}-20)\ (0.5\overset{H}{\underline{\quad}}-10)]$$

$$= \$\underline{\qquad\qquad\qquad}\ \text{carbon steel} \quad \boxed{78}$$

Flue gas valve (out) at main duct to create a bypass

$$\frac{\text{item } \overset{\text{Chart 4}}{\boxed{22}} \text{ acfm at } \underline{\qquad}{}^\circ\text{F}}{2{,}500} \Big/ \text{Boiler} = \frac{\boxed{22}}{2{,}500} = \underline{\qquad\qquad}\ \text{ft}^2 = 2w^2$$

$$W = \sqrt{\frac{\underline{\qquad\qquad}}{2}}\ \text{ft}^2;\ W \times 2 = \underline{\qquad} \times 2 = \underline{\qquad}\ \text{ft (height H)}$$

$$\text{Valve cost B} = (1.5 \times \overset{(H)}{\underline{\qquad}})\ [(141.6) \pm^{*} (4.5)\ (\overset{(H)}{\underline{\quad}}-20)\ (0.5\overset{(H)}{\underline{\quad}}-10)]$$

$$= \underline{\qquad\qquad\qquad}\ \text{stainless steel} \quad \boxed{79}$$

Flue gas valve (in) to absorber and/or venturi train

$$\frac{\text{item } \overset{\text{Chart 4}}{\boxed{22}} \text{ acfm at } \underline{\qquad}{}^\circ\text{F} \Big/ \text{Boiler}}{\boxed{24}\ \text{(No. of venturis or absorbers)} \times 3{,}500} = \text{Area, ft}^2$$

FLUE GAS SHUTOFF AND BYPASS VALVES (continued)

$$\frac{\overline{22}}{\boxed{24}\underline{\hspace{2cm}} \times 3{,}500} = \underline{\hspace{3cm}} = \text{Area, ft}^2 = 2w^2$$

$$W = \sqrt{\frac{\underline{\hspace{2cm}}}{2}}\ \text{ft}^2;\ W \times 2 = \underline{\hspace{2cm}} \times 2 = \underline{\hspace{2cm}}\text{ft, height (H)}$$

Valve cost C

$$= (\text{Height (H)} + 0.5\ \text{Height (H)}\ [(99.1)-(3.1)(H-20)\ (0.5H-10)]$$

$$= (1.5 \times \overset{(H)}{\underline{\hspace{1cm}}})\ [(99.1)-(3.1)\ (\overset{(H)}{\underline{\hspace{1cm}}}-20)\ (0.5\overset{(H)}{\underline{\hspace{1cm}}}-10)]$$

$$= \underline{\hspace{3cm}}\text{carbon steel} \qquad \boxed{80}$$

Valve cost D =

$$\left(\frac{\text{Chart 4, item } \boxed{24}}{\text{No. of venturis and/or absorbers}}\right) \times (\text{valve cost}_C\ \boxed{80}) = \qquad \boxed{81}$$

$$= (\underline{\hspace{2cm}}) \times (\underline{\hspace{3cm}}) = \$\underline{\hspace{3cm}}\boxed{81}$$

Flue gas valve (out) from absorber and/or venturi

$$\frac{\text{Chart 4, item } \boxed{23}}{\frac{1.08 \text{ acfm at } 175°\text{F}}{2{,}500}} \Big/ \text{Venturi and/or absorber} = \text{ft}^2 = 2w^2$$

$$0.000432 \times \overset{\boxed{23}}{\underline{\hspace{2cm}}} = \underline{\hspace{2cm}}\text{ft}^2$$

$$W = \sqrt{\frac{\underline{\hspace{2cm}}}{2}}\ \text{ft}^2;\ W \times 2\underline{\hspace{2cm}} \times 2 = \underline{\hspace{2cm}}\text{ft, (H)}$$

Valve cost_E =

$$= (1.5\overset{(H)}{\underline{\hspace{1.5cm}}})\ [(141.6)-(4.5)\ (\overset{(H)}{\underline{\hspace{1.5cm}}}-20)\ (0.5\overset{(H)}{\underline{\hspace{1.5cm}}}-10)]$$

$$= \$\underline{\hspace{3cm}}\text{stainless steel}\ \boxed{82}$$

Valve cost_F =

$$\left(\frac{\text{Chart 4, item } \boxed{24}}{\text{No. of venturis and/or absorbers}}\right) \times (\text{valve cost}_E\ \boxed{82}) = \qquad \boxed{83}$$

$$= (\underline{\hspace{2cm}}) \times (\underline{\hspace{3cm}}) = \$\underline{\hspace{3cm}}\boxed{83}$$

Valving cost per boiler

$$\text{Valve cost}_G = \boxed{78} + \boxed{79} + \boxed{81} + \boxed{83} = \boxed{84}$$

$$= V_A \quad V_B \quad V_D \quad V_F$$

$$= \underline{\hspace{2cm}} + \underline{\hspace{2cm}} + \underline{\hspace{2cm}} + \underline{\hspace{2cm}}$$

$$= \$\underline{\hspace{3cm}}\text{total valve cost} \qquad \boxed{84}$$

FLY ASH SLUDGE PUMP TO ASH POND COSTS

To determine the total pump cost for venturis, Chart 15:

Enter from page D-10 Chart 3, item $\boxed{18}$ on Chart 15, item $\boxed{85}$;

Enter head in feet on item $\boxed{86}$, if unknown and distance from pump to ash pond is approximately 2000 feet and level use 150 foot head, if another head is used enter on item $\boxed{86}$ and record ______ $\boxed{86}$;

Connect $\boxed{85}$ and $\boxed{86}$ and extend to $\boxed{87}$

Enter specific gravity of sludge on item $\boxed{88}$, if unknown use 1.1, if another specific gravity is used enter on item $\boxed{88}$ and record ______

Connect $\boxed{87}$ and $\boxed{88}$ and extend to $\boxed{89}$

Connect $\boxed{89}$ and $\boxed{90}$ and extend to $\boxed{91}$, read and record cost per pump $___ $\boxed{91}$

Total pump cost:

$\boxed{91}$ + spare = 2 x $\boxed{91}$ = Total cost $\boxed{91}_T$

2 x ________ = ______ $\boxed{91}_T$

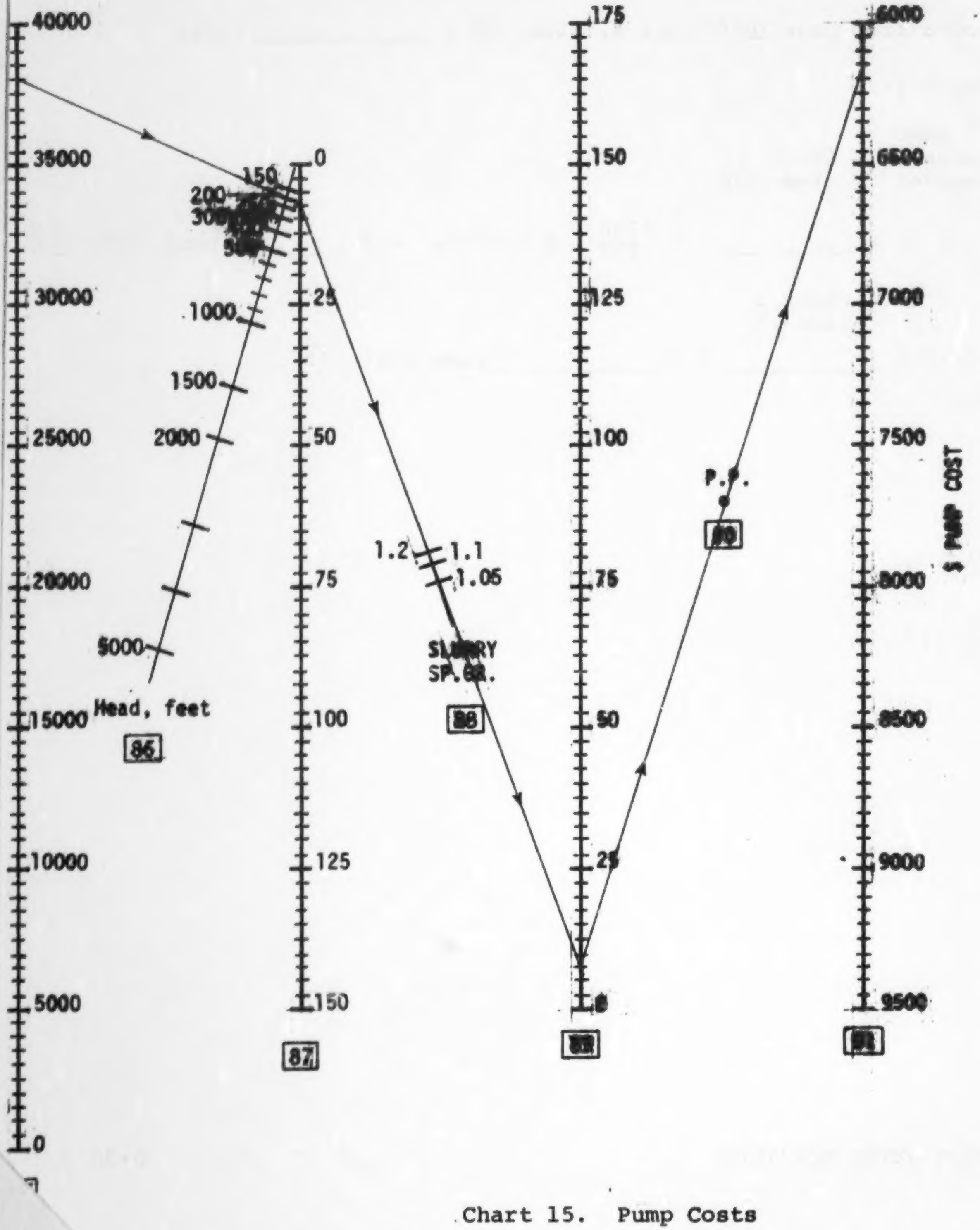


Chart 15. Pump Costs

FLY ASH RETURN WATER PUMP

To determine the total pump cost for water return

Record from page D-10 Chart 3, item $\boxed{19}$; ____________ lb/hr

Total pump cost:

$$\underset{\substack{\text{(1 pump}\\\text{plus 1}\\\text{spare)}}}{2} \quad \times \quad \underset{\text{Chart 3, item } \boxed{19}}{\underline{\hspace{3cm}}} \quad \times \quad \frac{\$200}{500} \quad \times \; 0.04314 = \$ \; \underline{\hspace{2.5cm}} \text{ pump cost } \boxed{92}$$

$$0.0433 \times \underset{\text{Chart 3 item } \boxed{19}}{\underline{\hspace{3cm}}} = \$ \; \underline{\hspace{3cm}} \text{ pump cost } \boxed{92}$$

WATER MAKE-UP PUMP

Record from page D-12 Chart 4, item $\boxed{22}$; __________ acfm at 125°F

Pump cost:

$$\frac{2 \times 0.167 \text{ lb } H_2O/\text{hr/acfm} \times \text{acfm at } 125^\circ F \; \boxed{22}}{500 \text{ lb/hr/gal/min.}} \times 0.0361 \times 200 = \$\_\_\_ \; \boxed{93}$$

Chart 4,
item $\boxed{22}$

$$= 0.0048 \times \underline{\hspace{3cm}} = \$ \underline{\hspace{4cm}} \; \boxed{93}$$

MgO, 3 DAY OPERATING AND 12 DAY STORAGE SILOS

To determine the cost of the material handling equipment including the following; silos, bucket elevators, conveyors, trippers, in-ground receiving hoppers and weigh feeders to slurry tanks, Table 16.

Record from page D-7 Chart 2, item $\boxed{10}$ or $\boxed{10}_c$; ________ lb/hr MgO

$\boxed{10}$ or $\boxed{10}_c$

$\frac{\_\_\_\_\_\_\_\_}{2000}$ = ____________ ton/hr MgO $\boxed{94}$

Table 16.

ton/hr MgO	$\boxed{95}$	$\boxed{96}$	$\boxed{97}$	$\boxed{98}$
0 - 0.5				9,000
0.5 - 2.5				15,000
2.5 - 6.25				36,000
6.25 - 10.83	25,700	102,800	36,600	165,000
10.83 - 21.67	35,100	140,400	41,800	217,300
21.67 - 33.3	44,400	177,600	47,000	269,000
33.3 - 44.17	53,700	214,800	54,800	323,300
44.17 - 55.42	63,100	252,400	61,400	376,900
55.42 - 66.67	72,400	289,600	64,800	426,800
66.67 - 90	96,300	385,200	66,900	548,400

Compare $\boxed{94}$ with Chart 16 ton/hr MgO column

Select tonnage range that $\boxed{94}$ would encompass and move horizontally to the right to column $\boxed{98}$ read and record: $ ________________ $\boxed{98}$

SLURRY PUMP AND TANK COSTS

To determine the slurry tank and pump cost, Chart 17:

Enter from page D-7 Chart 2, item $\boxed{10}$ on Chart 19 item 99 move vertically to item $\boxed{100}$ and then horizontally to the left for tank and pump cost $________________ $\boxed{101}$

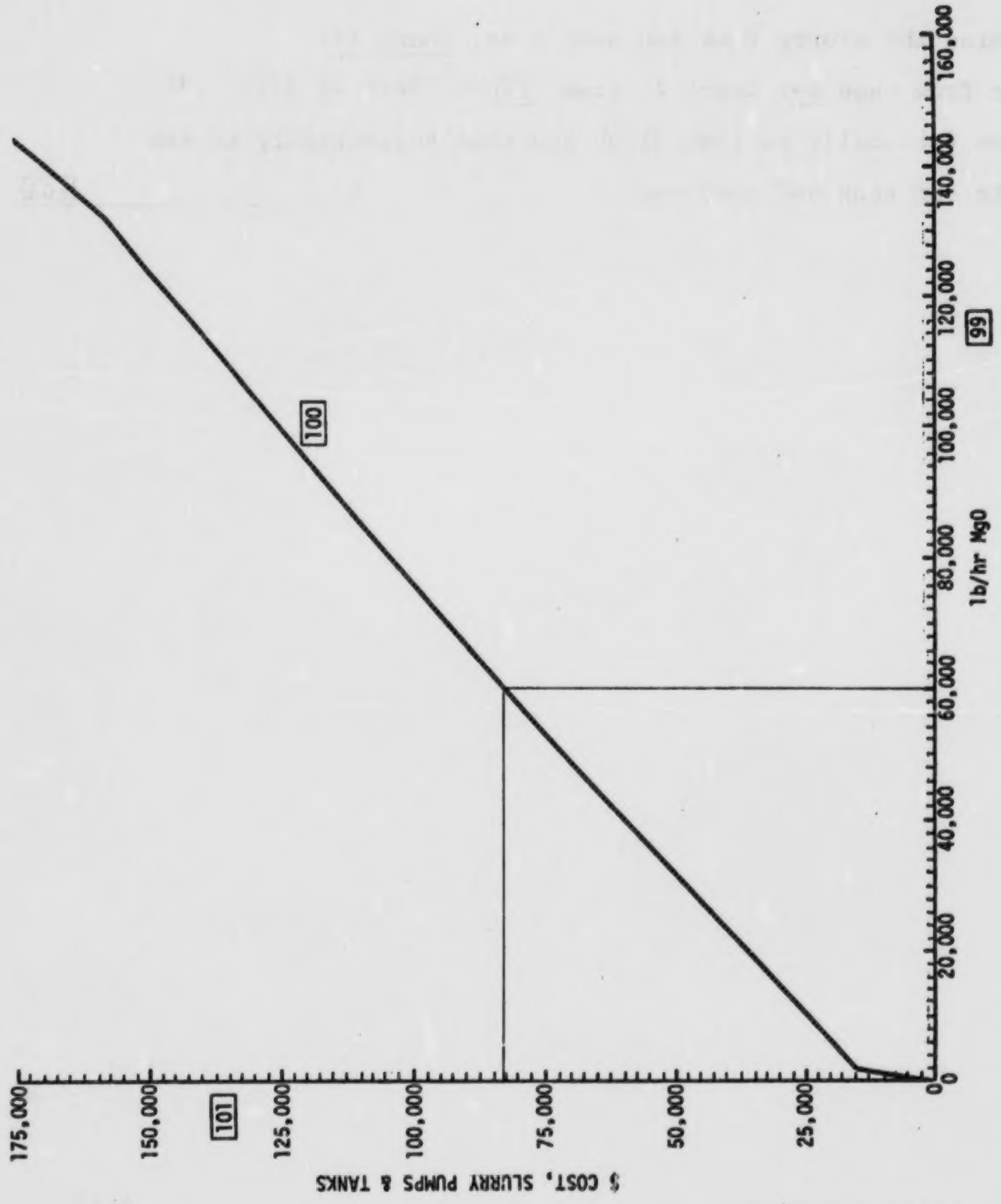


Chart 17. SLURRY PUMP AND TANK COST

CENTRIFUGE

To determine centrifuge costs, Chart 18:

Enter from page D-12Chart 4, item $\boxed{22}$ on Chart 18 item $\boxed{102}$

Connect item $\boxed{102}$ with the percent sulfur on $\boxed{103}$,
extend to $\boxed{104}$, read and record: ________ $\boxed{104}$

Enter $\boxed{104}$ on $\boxed{105}$ and move vertically to $\boxed{106}$ and from
$\boxed{106}$ horizontally to $\boxed{107}$, read and record

Total centrifuge cost $ ____________ $\boxed{107}$

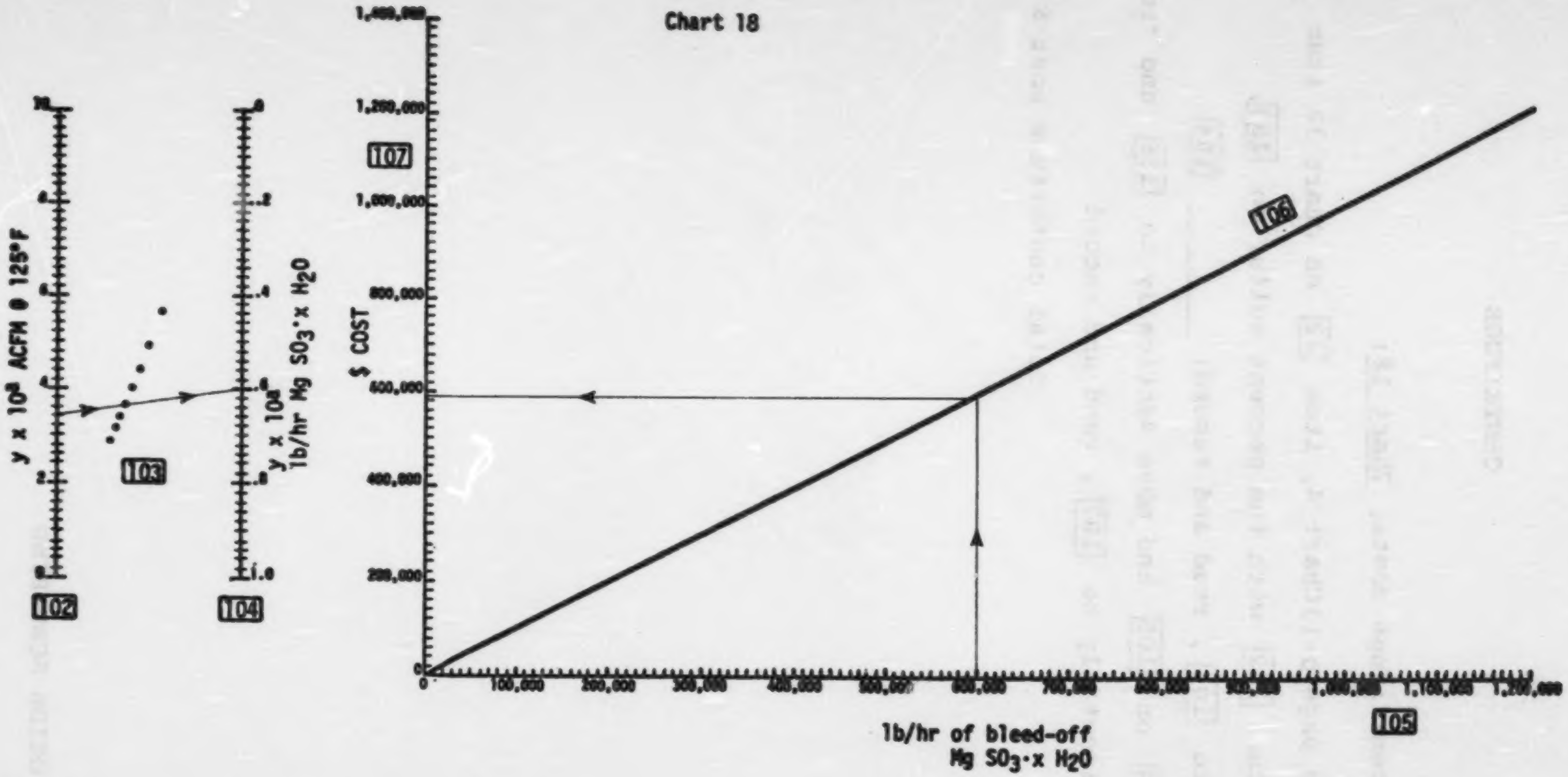


Chart 18. CENTRIFUGE COSTS

DRYER

To determine dryer costs, Chart 19:

Enter from page D-44, Chart 18, item $\boxed{104}$ on Chart 19 item $\boxed{108}$

Move vertically from item $\boxed{108}$ to $\boxed{109}$ and then horizontally to $\boxed{110}$, read and record

$ _______________ $\boxed{110}$

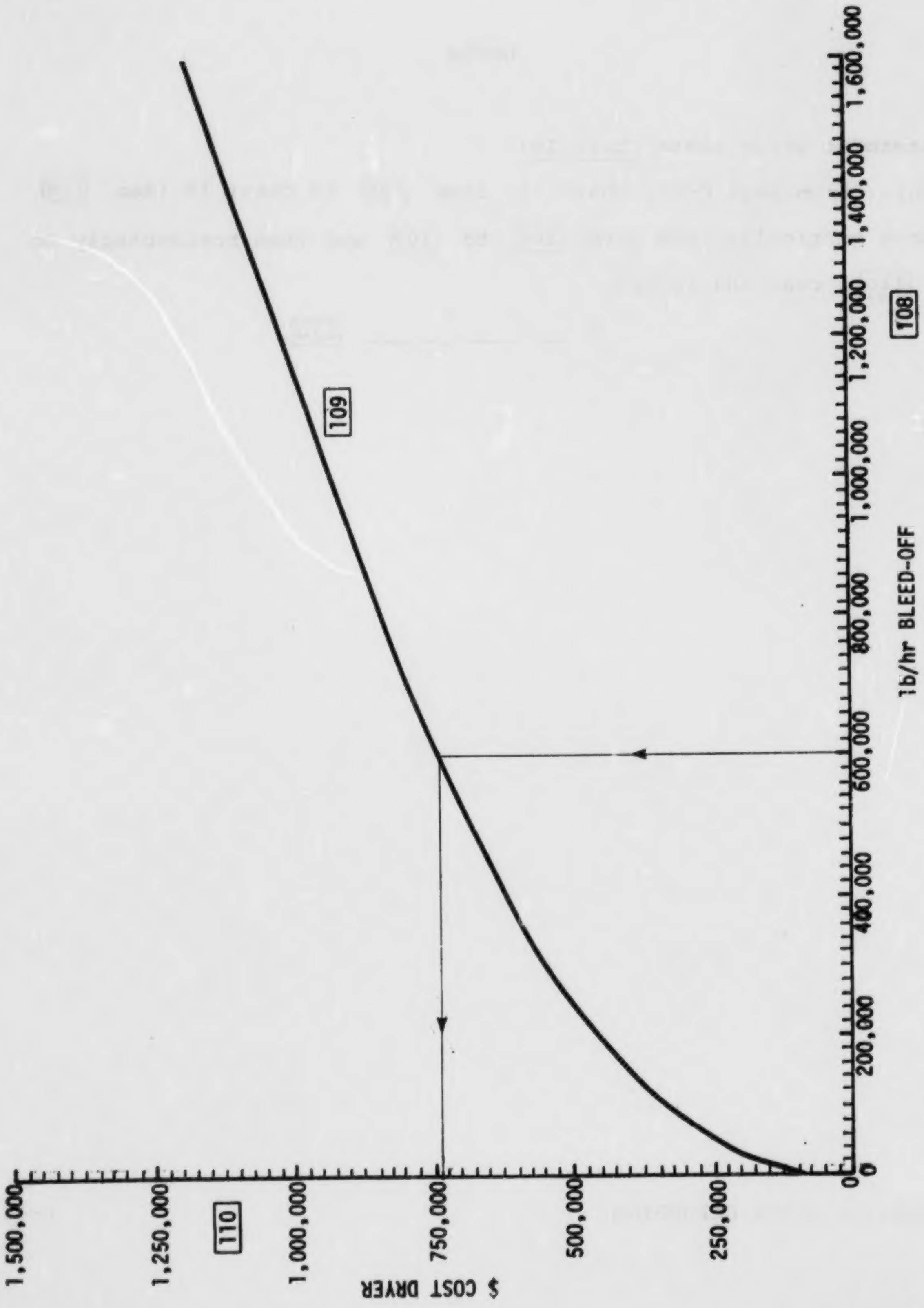


Chart 19. DRYER COSTS

CENTRATE TANK AND PUMP

To determine costs for centrate tank and pump, Chart 20:

Enter from page D-44, Chart 18, item $\boxed{104}$ on Chart 20, item $\boxed{111}$

Move vertically to $\boxed{112}$ and from $\boxed{112}$ move horizontally to $\boxed{113}$, read and record costs of 2 tanks and 2 pumps with a spare pump

$ ________________ $\boxed{113}$

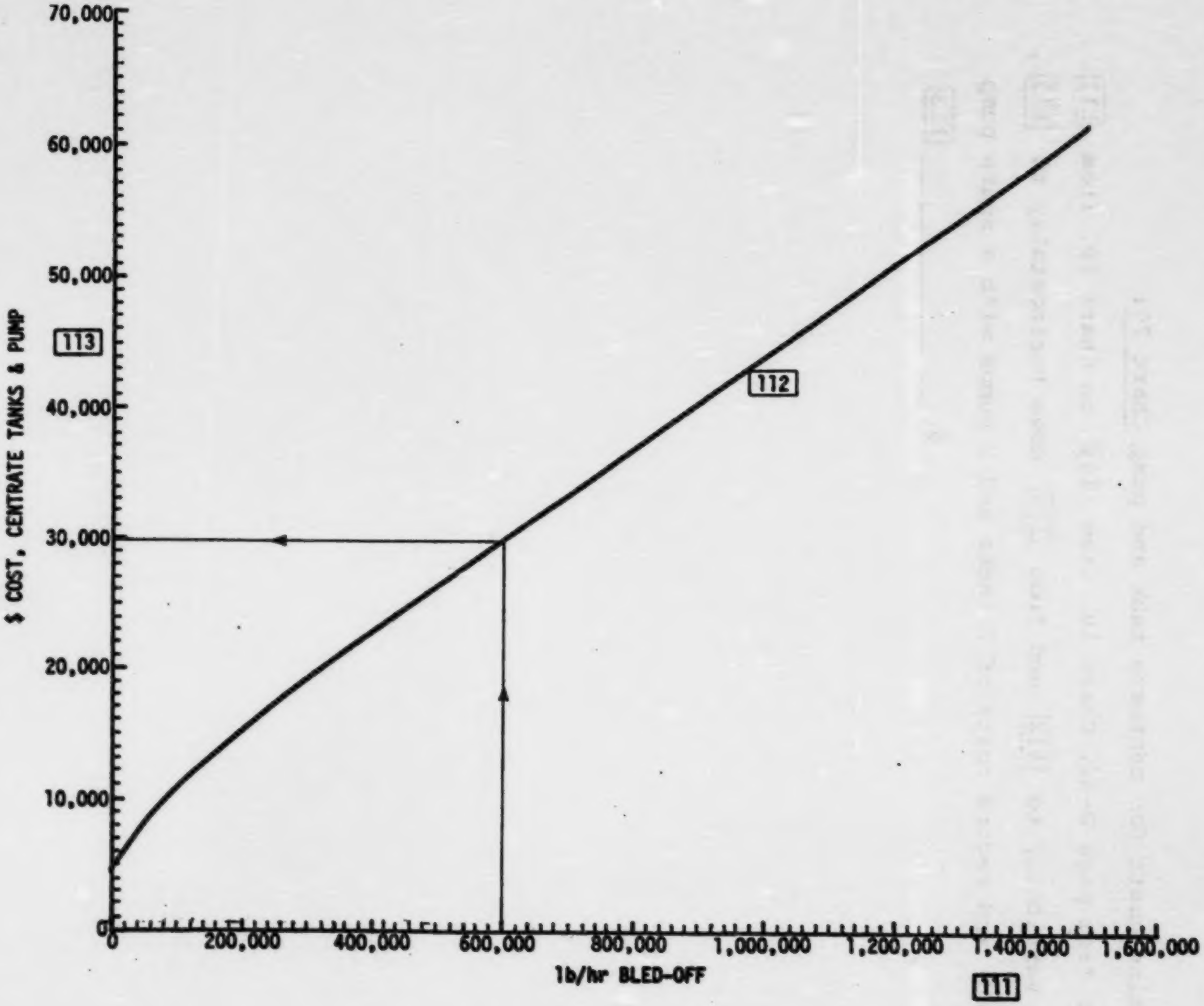


Chart 20. CENTRATE TANKS & PUMP COSTS

BREAKER HAMMERMILL/RUN OUT CONVEYOR/STORAGE SILOS

To determine cost of breaker hammermill, 24 foot vibrating runout conveyor, bucket elevator, $MgSO_3$ storage silo and coke storage silo with bucket elevator, and in-ground receiving hopper, Table 21.

ton/hr of $MgSO_3$ = 0.00137 x %S in coal from data sheet x lb/hr coal from data sheet = $\boxed{114}$

= 0.00137 x 0._______ x _________ = ____________ $\boxed{114}$

Table 21

ton/hr $MgSO_3$ $\boxed{115}$	Mill and vib. conv. $\boxed{116}$	Bucket elev., conv. and tripper $\boxed{117}$	$MgSO_3$ storage silos $\boxed{118}$ $	Coke storage silos and Bucket elev. $\boxed{119}$	Total cost $\boxed{120}$
0 - 1	12,500	5,600	1/9000	14,600	42,000
1 - 1.67	12,500	5,700	1/12,000	14,600	45,000
1.67 - 2.5	12,700	5,800	1/15,000	14,600	48,000
2.5 - 3.33	12,700	6,000	1/18,000	14,600	51,000
3.33 - 5	13,000	6,200	1/21,000	14,600	55,000
5 - 6.67	13,100	14,300	2/18,000	14,600	78,000
6.67 - 8.33	13,200	14,600	2/21,000	14,600	84,000
8.33 - 10	13,400	14,900	2/24,000	14,600	91,000
10 - 13.33	13,600	18,500	3/21,000	14,600	110,000
13.33 - 16.67	13,700	19,400	3/24,000	14,600	120,000
16.67 - 20	14,100	20,100	4/21,000	14,600	133,000
20 - 25	14,300	21,700	5/21,000	14,600	156,000

If $\boxed{114}$ is greater than 25 ton/hr divide $\boxed{114}$ by number of whole units required $\boxed{121}$

$\frac{\boxed{114}}{\boxed{121}}$ = _________ = ___________ (equal to or less than 25 ton/yr) $\boxed{122}$

BREAKER HAMMERMILL/RUN OUT CONVEYOR/STORAGE SILOS (continued)

Enter $\boxed{114}$ or $\boxed{122}$ in column $\boxed{115}$ Table 21, selecting the proper ton/hr, then move horizontally to column $\boxed{120}$, read and record:

$ ______________ $\boxed{120}$

If $\boxed{122}$ is used:

$\boxed{120}$ x $\boxed{121}$ = Total cost $\boxed{123}$

__________ x ______________ = $ ______________ $\boxed{120}$

DRYER DUST COLLECTOR, BAGHOUSE AND BLOWER

To determine the costs of dryer cyclone dust collecter, fabric baghouse and blower, Chart 22:

From page D-44 item $\boxed{104}$, read and record

lb/hr bleed off ____________ $\boxed{104}$

If item $\boxed{104}$ exceeds 1.6 x 10^6 lb/hr;

$$\frac{\boxed{104}}{2} = \frac{\boxed{104}\ \underline{\hspace{3em}}}{2} =$$

____________ $\boxed{124}$

Enter item $\boxed{104}$ or item $\boxed{124}$ on Chart 22, item $\boxed{125}$ move vertically upward to $\boxed{126}$ and then horizontally to $\boxed{127}$, read and record:

Cost of equipment $____________ $\boxed{127}$

Total cost:

$\boxed{127}$ x $\boxed{124}$ = cost of dust collector, baghouse and blower

____________ x ____________ = $ ____________ $\boxed{128}$

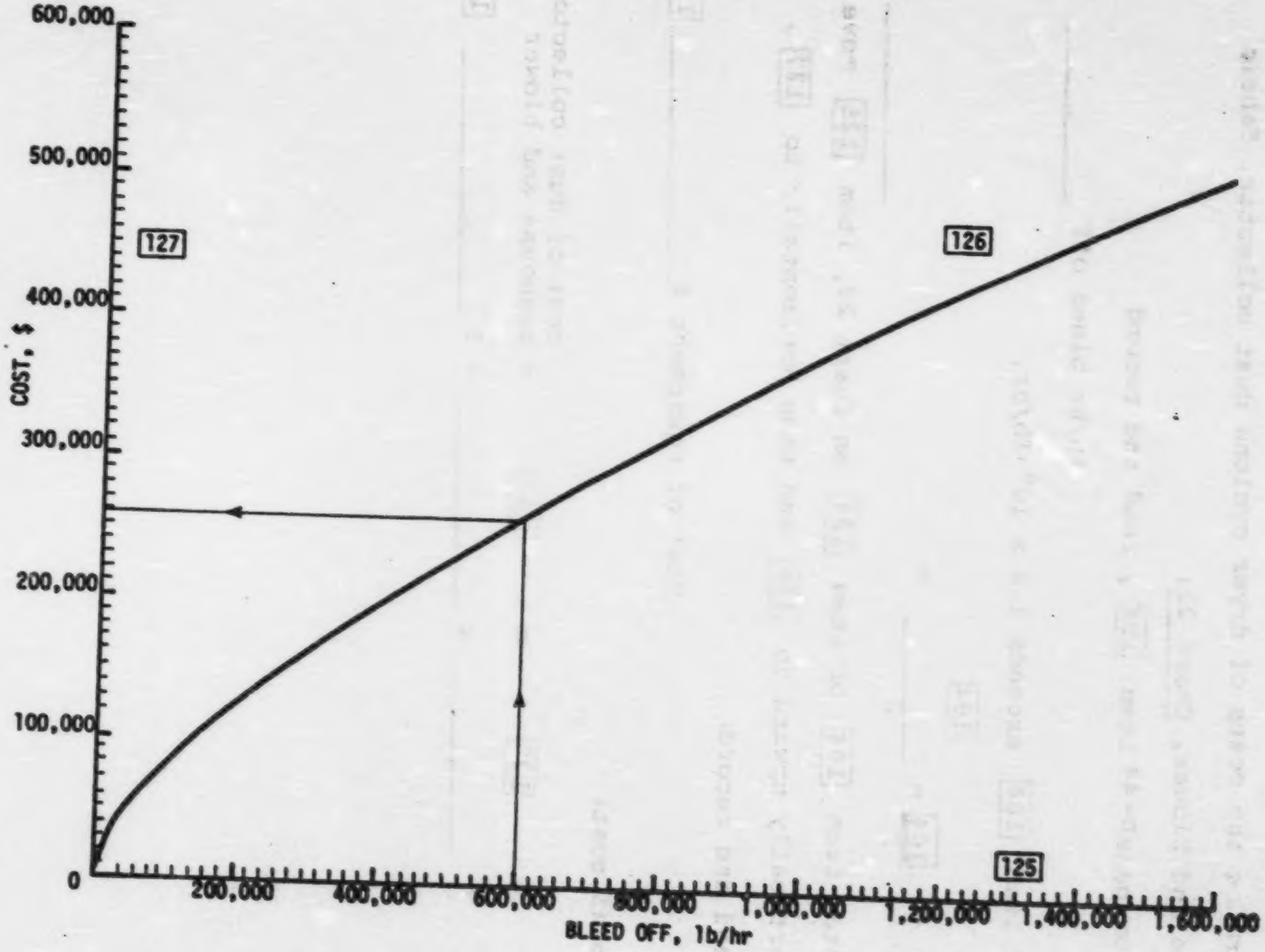


Chart 22. DUST COLLECTION

CALCINER

To determine the costs of a calciner, Chart 23:

Enter from page D-44 Chart 18 item $\boxed{104}$ on Chart 23 item $\boxed{129}$ move vertically to item $\boxed{130}$ and from item $\boxed{130}$ horizontally to item $\boxed{131}$, read and record

Calciner cost, $ ______________ $\boxed{131}$

CYLCONE DUST COLLECTOR AND FABRIC FILTER BAGHOUSE AND BLOWER

To determine the costs of the dust collectors and blower:

From page D- 52

Chart 22

Item $\boxed{128}$

Read and record

________ x 0.9 = $ ____________ $\boxed{132}$ dust collectors and blower cost

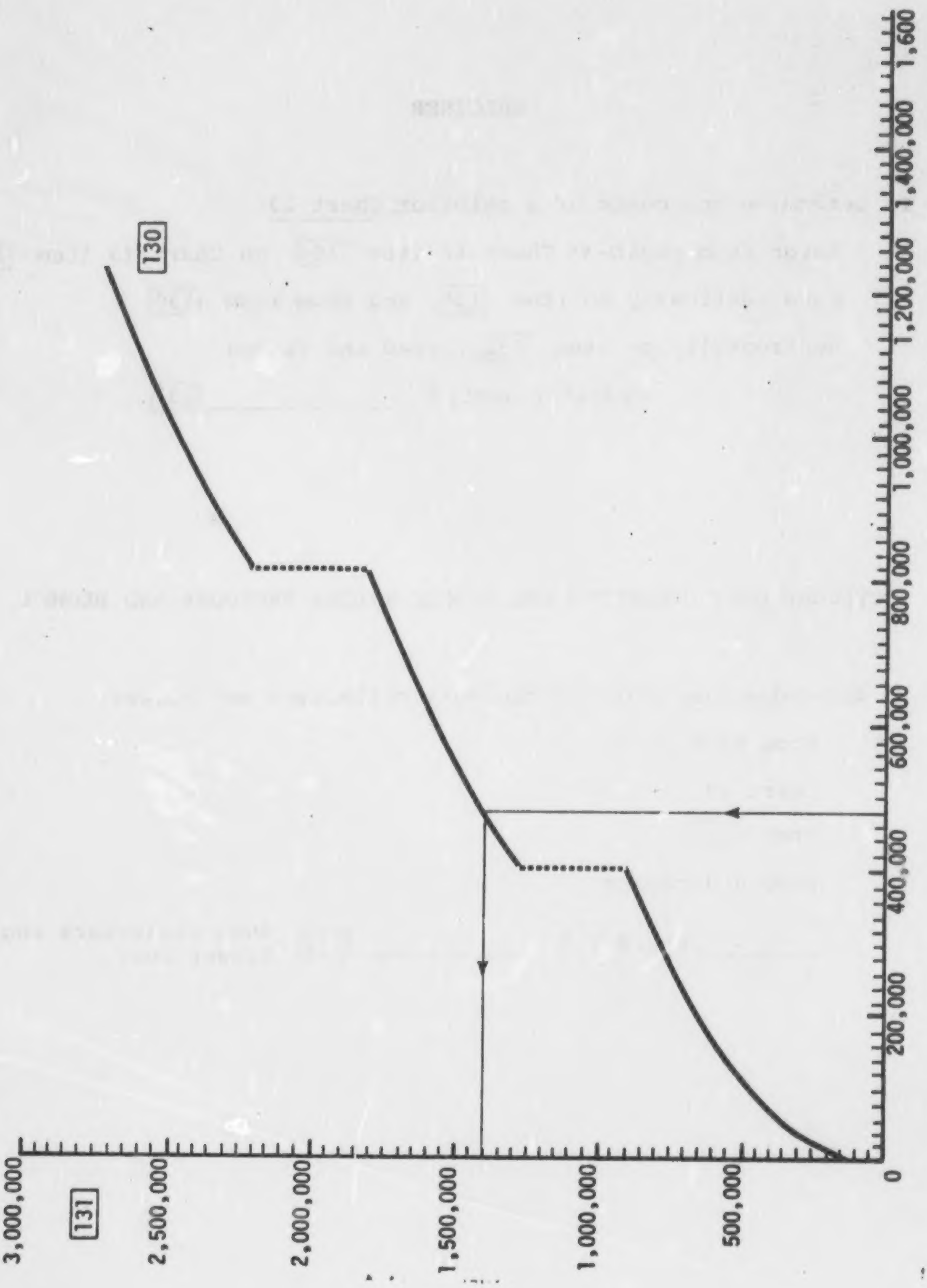


Chart 23. CALCINER COST

HAMMERMILL/RUN OUT CONVEYOR/STORAGE SILOS

To determine the cost of the hammermill, run out 24' vibrating conveyor, bucket elevator, MgO storage silo and discharge unit, Chart 24:

From page D-49,Table 21 item $\boxed{114}$ record here __________ $\boxed{114}$

$\boxed{114}$ x 0.39 = ton/hr MgO $\boxed{133}$

______ x 0.39 = ________ $\boxed{133}$ ton/hr/MgO

Enter $\boxed{133}$ on Chart 24, item $\boxed{134}$ and move vertically upward to $\boxed{135}$ and then horizontally to $\boxed{136}$, read and record

$ __________________ $\boxed{136}$

cost MgO storage
silos, conv., mill

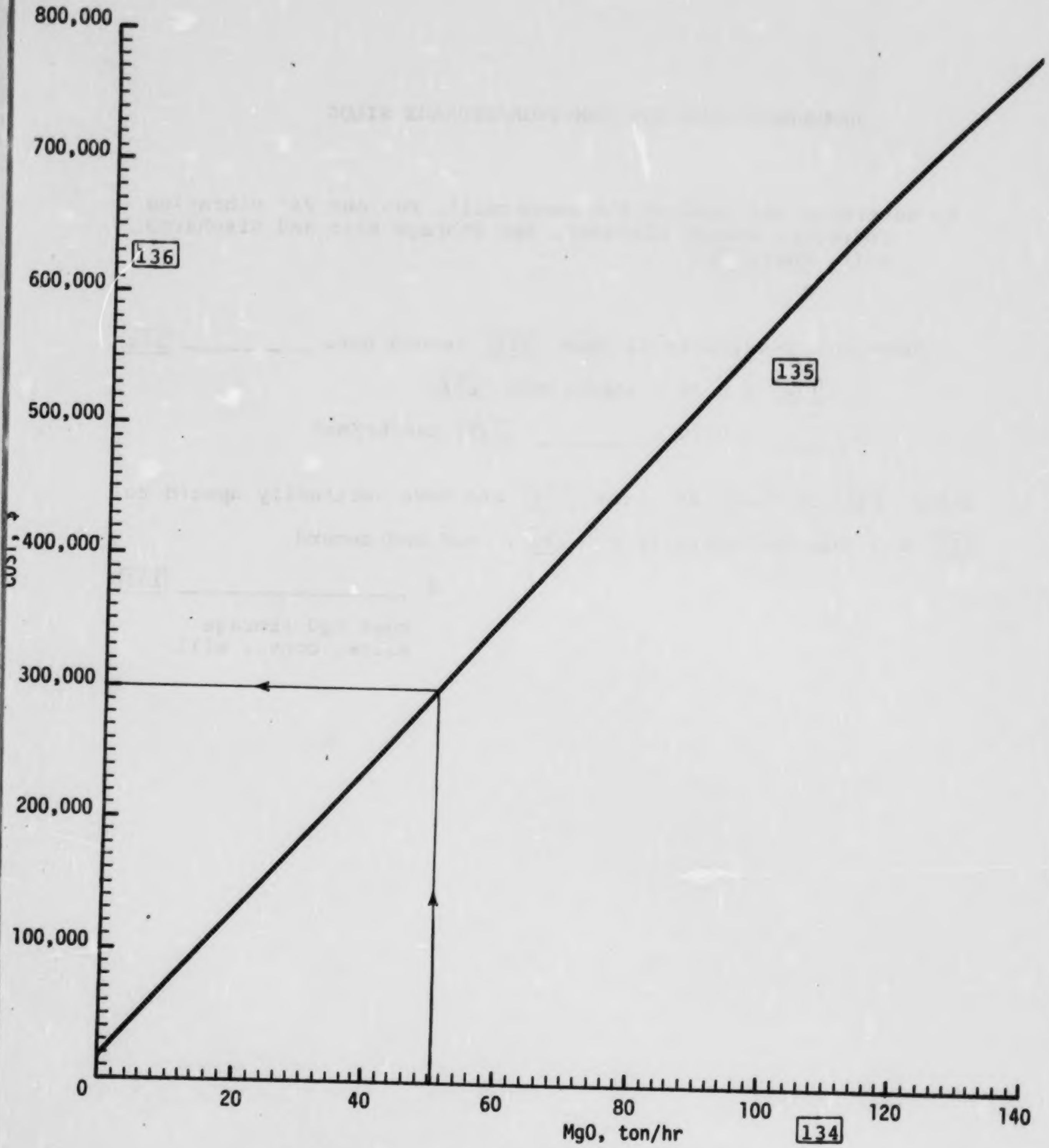


Chart 24. MILL/CONVEYOR/SILOS COSTS

POND ACREAGE AND POND EXCAVATING/DIKING COSTS

To determine the cost of pond acreage, excavating/diking costs,

Chart 25:

Enter from page D-10 Chart 3, item 15_A (ton/hr dry flyash) on Chart 25 item $\boxed{137}$ then move vertically upward to the respective weighted capacity factor, item $\boxed{138}$

From item $\boxed{138}$ move horizontally left to item $\boxed{139}$ (acre-ft/yr) and reference line $\boxed{140}$ and read: ______________ $\boxed{139}$

Select plant remaining life on item $\boxed{141}$

Connect items $\boxed{140}$ and $\boxed{141}$ and extend to item $\boxed{142}$ (pond acre-ft) read and record: ______________ $\boxed{142}$

From item $\boxed{142}$ move horizontally left to item $\boxed{143}$ (pond reference scale)

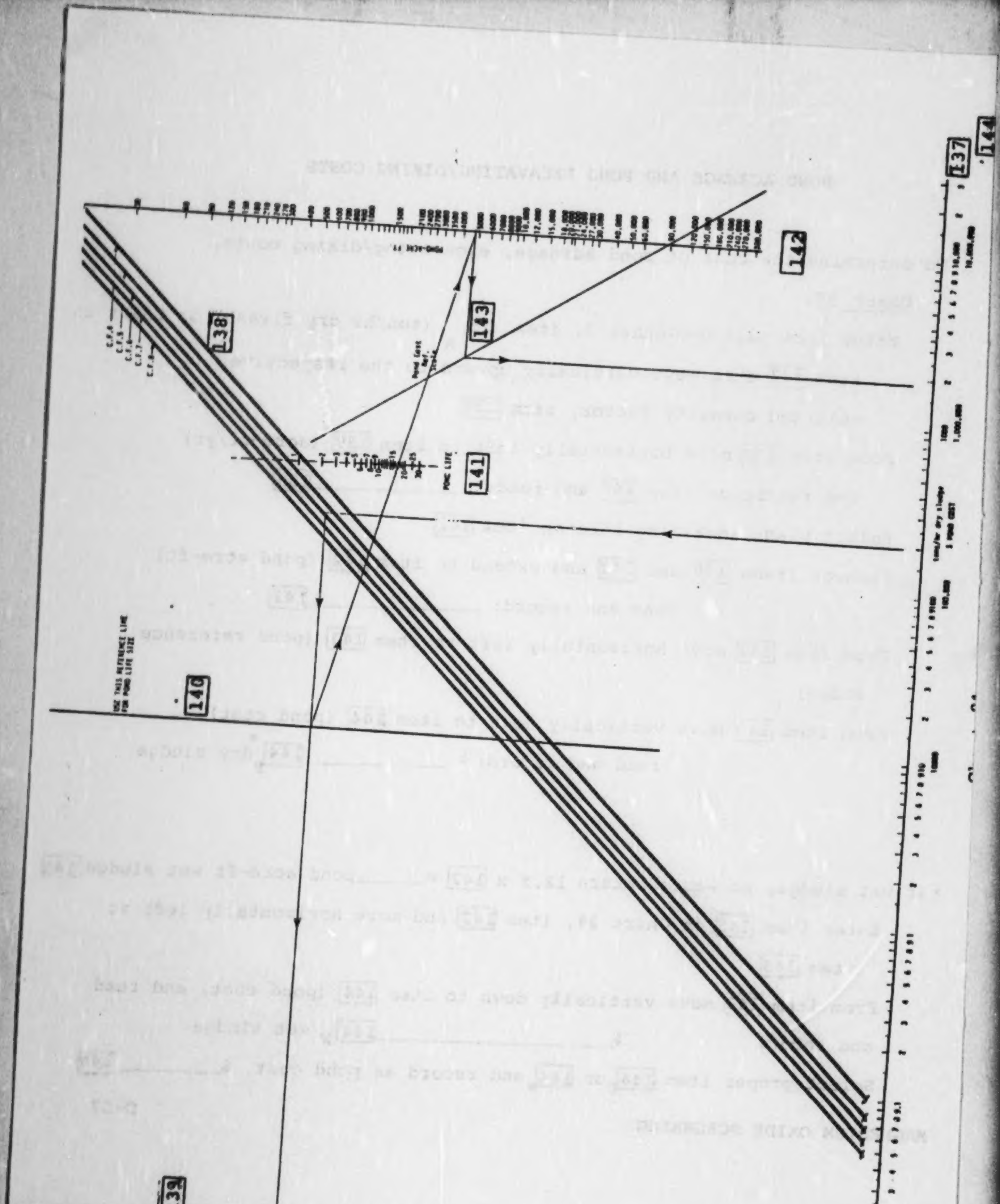
From item $\boxed{143}$ move vertically down to item $\boxed{144}$ (pond cost) read and record: $ ______________ $\boxed{144}_P$* dry sludge

*If wet sludge, no waste return 12.5 x $\boxed{142}$ = ______ pond acre-ft wet sludge $\boxed{145}$

Enter item $\boxed{145}$ on Chart 24, item $\boxed{142}$ and move horizontally left to item $\boxed{143}$

From item $\boxed{143}$ move vertically down to item $\boxed{144}$ (pond cost) and read and record $ ______________ $\boxed{144}_W$ wet sludge

Select proper item $\boxed{144}_P$ or $\boxed{144}_W$ and record as pond cost, $ __________ $\boxed{146}$



MAGNESIUM OXIDE SCRUBBING

EQUIPMENT COST - MgO

	Equipment	Item	Cost $
1.	Absorber	$\boxed{27}$ A	
2.	Venturi and Absorber	$\boxed{27}$ V+A	
3.	Venturi	$\boxed{27}$ V	
4.	Absorber and/or Venturi holding tanks agitators	$\boxed{35}$ T	
5.	Absorber and/or Venturi holding tanks	$\boxed{39}$ T	
6.	Circulation holding tank pumps	$\boxed{49}$ T	
7.	I. D. Fans	$\boxed{52}$	
8.	Heat exchangers	$\boxed{55}$	
9.	Soot blowers	$\boxed{59}$	
10.	Ducting	$\boxed{70}$	
11.	Bypass valving	Σ $\boxed{84}$	
12.	Sludge pump	$\boxed{91}$ T	
13.	Water return pump	$\boxed{92}$	
14.	Water make-up pump	$\boxed{93}$	
15.	3 and 12 day storage silos	$\boxed{98}$	
16.	Slurry pumps and tank	$\boxed{101}$	
17.	Centrifuge	$\boxed{107}$	
18.	Dryer	$\boxed{110}$	
19.	Centrate tank and pump	$\boxed{113}$	
20.	$MgSO_3$ storage silos, conv. hammermill	$\boxed{120}$ or $\boxed{123}$	
21.	Baghouse, dust collector, etc	$\boxed{127}$ or $\boxed{128}$	
22.	Calciner	$\boxed{131}$	
23.	MgO storage silo, conv. hammermill	$\boxed{136}$	
24.	New roadways or RR siding at $50/ft., estimated length		
	Total equipment cost $		

EQUIPMENT COST

Total equipment cost from page D-59

Year of FGD system operation

Select from cost factor index multiplier from page D-61 for the year above

Predicted equipment costs:

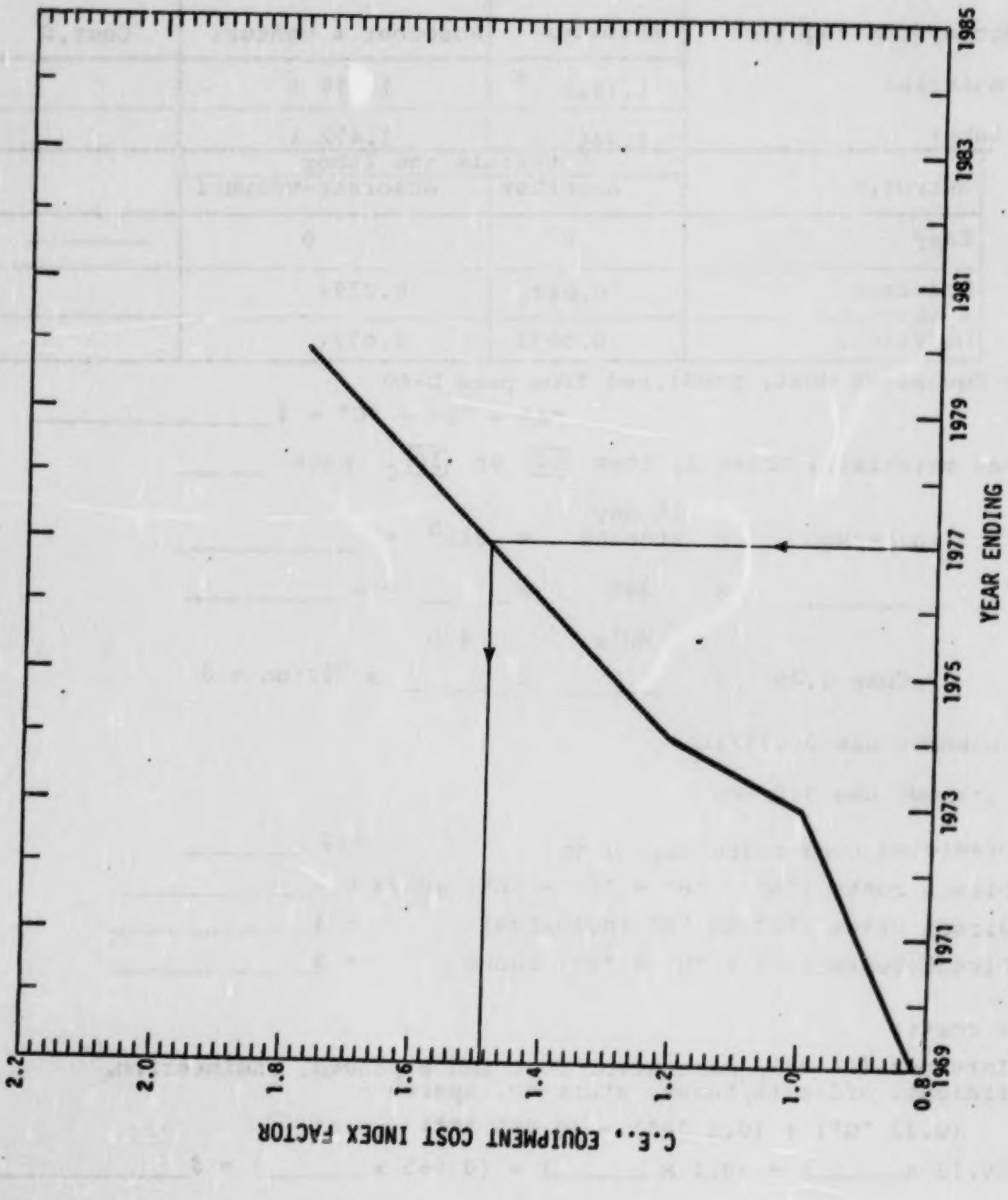
(total costs) x (cost factor index multiplier)

(__________) x (______________) = $_________

Predicted pond cost

= Pond cost from 145 x cost factor index multiplier

= ______________ x _____________ = $__________________


C.E., EQUIPMENT COST INDEX FACTOR
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
YEAR ENDING
1969
1971
1973
1975
1977
1979
1981
1983
1985

CAPITAL INVESTMENT COSTS--MgO

Direct costs:

Select system required	Absorber	Absorber & venturi	Cost,$
"A" Material	1.7913 λ[a]	1.776 λ	
"B" Labor	1.486 λ	1.472 λ	
	Materials and labor		
"C" Retrofit	Absorber	Absorber-venturi	
Easy	0	0	________
Moderate	0.047λ	0.039λ	
Difficult	0.093λ	0.077λ	

[a] λ = Equipment cost, predicted from page D-60

"A" + "B" + "C" = $________________

"D" Raw materials: Chart 2, item $\boxed{10}$ or $\boxed{10}_C$ page ______

lb/hr MgO x 15 day storage x $lb[b] = ____________

__________ x 360 x ______ = $ ____________

Coke 2.25 x MW's ________ x % S _______ x [c]$/ton = $

[b] If unknown use 0.075/lb

[c] If unknown use $40/ton

"E" predicted pond costs page D-60 = $ ________

"F" Direct costs ("A" + "B" + "C" + "E") above = $______________

"G" Direct costs ("A" to "E" inclusive) = $______________

"H" Direct costs ("A" + "B" + "C") above = $______________

Indirect costs:

"J" Interest (at 8%), contractor fees and expenses, engineering, freight, off-site, taxes, start-up, spares -

(0.33 "G") + (0.1 "H") + (0.065 "F") =

(0.33 x______) + (0.1 x______) + (0.065 x______) = $_____________

CAPITAL INVESTMENT COSTS--MgO (continued)

"K" Contingency:
0.2 ("J" + "F") = 0.2 (__________+__________) = $______________

"L" Total costs for capital investment

"G" + "J" + "K" =__________+__________+__________ = $______________

Cost/Kilowatt:

$$\frac{\text{L}}{\text{MW's} \times 1{,}000} = \frac{\_\_\_\_\_\_\_\_\_\_}{\_\_\_\_\_ \times 1{,}000} =$$

$____________/KW

TOTAL ANNUAL OPERATING COSTS--MgO

Utilities -

Water: MgO scrubbing

77 gal./MW for 3.0% S coal $\boxed{147}$

±Δ 6.6 gal./MW for each ± 1.0% S in coal $\boxed{148}$

65 gal./MW for 3.0% S oil $\boxed{149}$

±Δ 5 gal./MW for each ± 1.0% S in oil $\boxed{150}$

MgO

(gal./MW ± gal./MW corr. for % S) x hr/yr x weighted capacity fact. x water costs/1000 gal.) = yearly cost water/MW $\boxed{151}$

$\boxed{147}$ or $\boxed{149}$ ± $\boxed{148}$ or $\boxed{150}$

(________ ± ________) x $\frac{\$0.02}{1000}$ x 8760 x cap. factor ________. = $/MW

$ ________ $\boxed{151}$ A

(Coal or Oil) ; (Base % S ; % S corr.) ; $\boxed{151}$ A x MW = $\boxed{152}$

(________) ; (_____ ; _____) ; ________ x ________ = $ ________ /yr

Reheat:

From page D-31 Chart 13, item 65 determine $/reheat
(see calculation sheet)

$ ____________ /yr $\boxed{65}$

For ΔT ________ °F

TOTAL ANNUAL OPERATING COSTS--MgO

Operating labor cost:

MW's	Men/Shift
100- 699	5
700-1200	5.33
1201-2500	6.33
2501-	7.16

Men/shift x hr/yr x $/hr =

__________ x 8760 x 6.50 =

__________ x 56,940 = $__________/yr $\boxed{153}$

Corrected cost: $\boxed{153} \times \left(\frac{\$/\text{hr (manpower)}}{6.50}\right) = \$$__________/yr $\boxed{153}_c$

Supervision:

0.15 x 56,940 x men/shift = $\boxed{154}$

8541 x__________ = $__________/yr $\boxed{154}$

Corrected cost: $\boxed{153}_c \times .15 = \$$__________/yr $\boxed{154}_c$

Maintenance:

Capital costs, total

0.046 x__________________ = $__________/yr $\boxed{155}$

Overhead:

Capital cost, total + Men/shift

(0.023 x__________) + (13,100 x______) =

(__________________)+(__________________)=

= $__________________/yr $\boxed{156}$

TOTAL ANNUAL OPERATING COSTS--MgO

Fixed costs -

A. $\frac{100}{\text{Plant life, yrs*}}$ = ____________ %/yr depreciation, straight-line

B Capital = %/yr ________ %

C. Taxes, insurance, interim replacement - 4.65%

Total fixed costs = $\frac{A + B + C}{100}$ = ______ % /yr fixed costs

(fixed costs,%/yr) x(total capital cost) =

(____________ %/yr) x(________________)= $ ____________ /yr $\boxed{157}$

Fly ash disposal

Pumping to another site, off-plant

$0.0011 \times \underset{\text{MW}}{\_\_\_\_\_\_\_\_} \times \underset{\text{KW/MW}}{1000} \times \underset{\text{\$/KWH** or ***}}{\_\_\_\_\_\_\_\_\_\_} \times \underset{\text{hr/yr}}{8760} \times \underset{\text{weighed C.F.}}{\_\_\_\_\_\_\_\_} =$

$9.64 \times \underset{\text{MW}}{\_\_\_\_\_\_\_\_} \times \underset{\text{\$/KWH** or ***}}{\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \times \underset{\text{weighed C.F.}}{\_\_\_\_\_\_\_\_\_\_} = \$ \_\_\_\_\_\_\_\_\_\_\_\_ \text{/yr}$ $\boxed{158}$

Truck fly ash disposal costs/14 miles:

$\frac{\text{\_\_\_\_ ton dry sludge/hr}}{\text{8.47 tons dry sludge/truck hr}} \times \$17.20 \times 1.1 \times 8760 \times CF =$

(57.25 min/trip) ($17.20/truck hr/driver)

From Chart 3, item $\boxed{15}_A$, tons dry sludge/hr ________________ $\boxed{15}_A$

$\underset{\boxed{15}_A}{\_\_\_\_\_\_\_\_\_\_\_\_} \times 19{,}570 \times \underset{\text{weighed CF}}{\_\_\_\_\_\_\_\_\_\_\_\_\_\_} = \$ \_\_\_\_\_\_\_\_\_\_\_\_ \text{/yr}$ $\boxed{159}$

* Plant life, years: either remaining boiler life in years from start of FGD system or 15 year life for FGD system, use lowest number of years for life.

** or *** see next page

TOTAL ANNUAL OPERATING COST--MgO

Raw materials -

MgO

Page D-7 Chart 2, item $\boxed{10}$ or $\boxed{10}_c$ ____ton/hr Mgo x hr/yr x

MgO make-up percent weighed C.F. x \$/ton[a] = cost/yr. $\boxed{145}$

= 8760 x C.F. x 10% x \$/ton[a] x Chart 2, item $\boxed{10}$ or $\boxed{10}_c$ =

= 8760 x ____ x 0.1 x ______ x ______ = \$ ______ $\boxed{160}$

Coke: 54.6 x MW x %S x capacity factor x \$/ton[b] = coke cost

54.6 x ____ x 0.____ x ______ x ______[b] = \$ ______ $\boxed{161}$

Oil: 955,000 x MW x %S x capacity factor x \$/gal[c] = Fuel oil costs drying calciner

955,000 x ____ x 0.____ x ______ x _____[c] = \$ ______ $\boxed{162}$

Utilities:

Electrical, use appropriate

MgO--burning coal = MW \$/KWH** or *** C.F.

= 1.57×10^5 x ____ x ____ x ____ = \$ ______/yr = (on coal/abs. + vent.) $\boxed{163}_{A+V}$

MW \$/KWH** or *** C.F.

= 1.50×10^5 x ____ x ____ x ____ = \$ _____/yr = (on coal/abs.) $\boxed{163}_{A}$

MgO--burning fuel oil

MW \$/KWH** or *** C.F.

1.07×10^5 x ____ x ____ x ____ = \$ _______/yr = (on oil/abs.) $\boxed{163}_{O}$

[a] If unknown use \$150/ton.

[b] If unknown use \$40/ton.

[c] If unknown use (\$12/bbl) \$0.2857/gal.

** If unknown use 0.00675/KWH based on coal at \$10/ton and 12,000 BTU.

*** If unknown use 0.0185/KWH based on oil at \$8.40/bbl and 149,000 BTU/gal.

TOTAL ANNUAL OPERATING COSTS--MgO

Summary sheet

		Item		Cost, $
1.	Water	152		______
2.	Reheat	155		______
3.	Operating labor	153	c	______
4.	Supervision	154	c	______
5.	Maintenance	155		______
6.	Overhead	156		______
7.	Fixed costs	157		______
8.	Sludge fly ash disposal, pumping	158		______
9.	Sludge fly ash disposal, trucking	159		______
10.	MgO	160		______
11.	Coke	161		______
12.	Oil	162		______
13.	Electrical	163	A+V	______
		163	A	______
		163	O	______

Total annual operating costs $______

Cost per kilowatt-hour:

$$\frac{\text{(total annual operating cost)}}{\text{hr/yr} \times \text{(plant rating in MW's)} \times 1{,}000 \times \text{(weighed capacity factor)}} =$$

$$\frac{(\qquad\qquad)}{8760 \times (\qquad\qquad) \times 1{,}000 \times (\qquad)} = \underline{\qquad\qquad}/\text{KWH}$$

APPENDIX E

WELLMAN-LORD SCRUBBING

NOTE: For purposes of clarity and continuity, Tables and Charts have been numbered sequentially in this Appendix with no differentiation between Tables and Charts.

INFORMATION REQUIRED

Boiler No.						
Type of furnace						
MW at maximum continuous						
Age of unit , years						
Life, years remaining						
Capacity factor, yr.____						
Maximum continuous fuel, ton/hr or gal./min						
Maximum continuous, MM BTU/hr						
acfm at___°F						
Fly ash/total ash, %						
Efficiency of existing control (particulate matter)						

Cost of electricity/KW (Plant) =$_______ . Cost of water/M gal. (Plant) = $_______________

Coal, cost/ton $_________

% sulfur by weight _________

% ash by weight _________

HHV, BTU/lb _________

Oil, cost/bbl $_________

% sulfur by weight _________

BTU/gal _________

Specific Gravity _________

SO$_2$ permissible _________ lb SO$_2$/MM BTU }

Fly ash permissible_________ lb fly ash/MM BTU } State or Federal regulations

INFORMATION REQUIRED (continued)

Estimated land cost per acre (current) $

Possible interference determining the location of flue gas desulferization (FGD) system:

Congestion between stack and plant ☐ Yes ☐ No

Congestion between stack and/or plant with property line, coal pile, etc., ☐ Yes ☐ No

Identify problem areas and location: ____________________

____

Terrain ____________________

____

Conduits ____________________

____

Possible obstructions ____________________

____

Source of Na_2CO_3 available ____________________

and % purity ________

SO$_2$ EMISSION DETERMINATION

To determine the SO$_2$ emissions (lb/MM BTU) in the flue gas, Chart 1:

Enter % sulfur by weight of fuel (oil or coal) on $\boxed{1}$

Enter heating value of fuel (BTU/lb) on $\boxed{2}$

Connect $\boxed{1}$ and $\boxed{2}$ and extend to $\boxed{3}$ and record and read:

SO$_2$ emissions (lb/MM BTU) in flue gas ____________ $\boxed{3}$

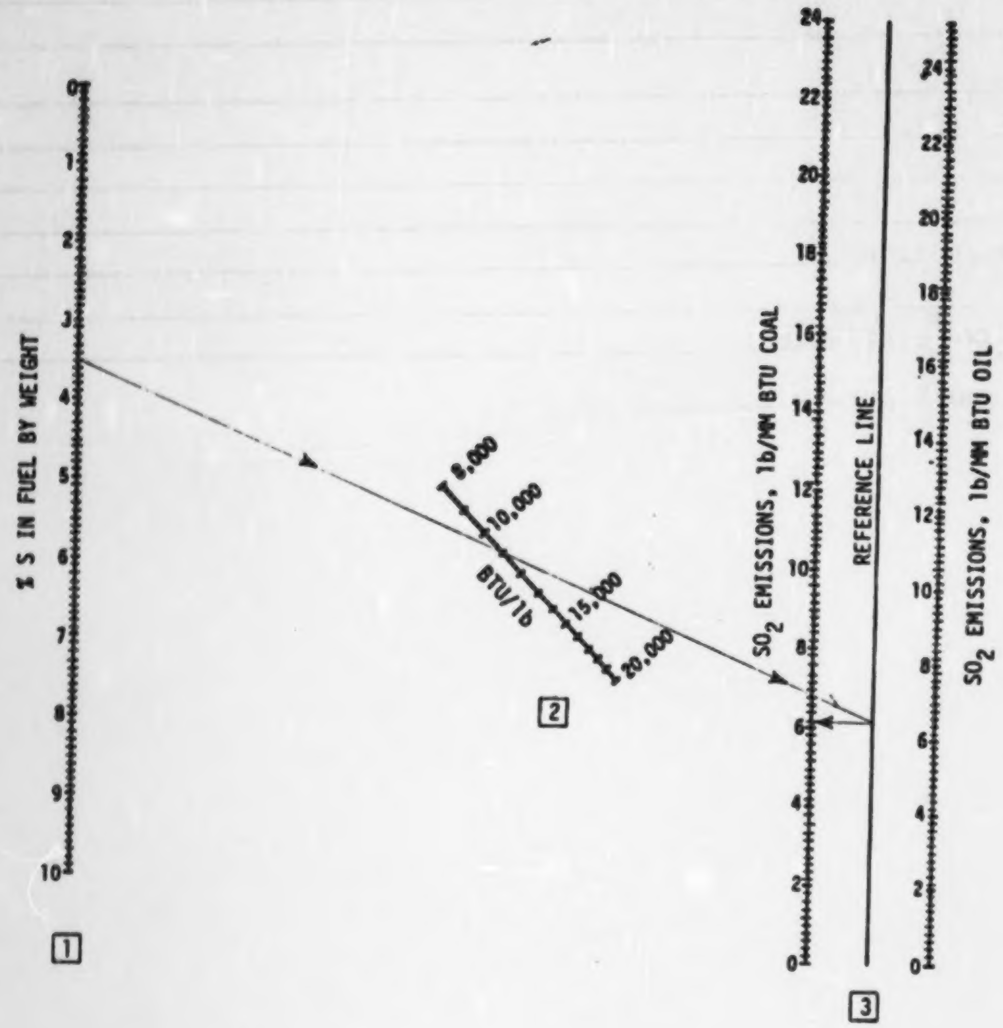


Chart 1. SO$_2$ EMISSION DETERMINATION

Assumptions:

(1) 95% of sulfur in coal converted to SO$_2$
(2) 100% of sulfur in oil converted to SO$_2$

SO_2 REMOVAL REQUIREMENTS

To calculate SO_2 emissions (lb/MM BTU) to be removed:

Enter from page E-4, Chart 1, item 3 the lb/MM BTU ________ 3

Enter from the data sheet, allowable SO_2 emissions (lb/MM BTU) from the State or Federal regulations ________ 4

Subtract 4 from 3 to calculate SO_2 emissions (lb/MM BTU) to be removed ________ 5

Na_2CO_3 REQUIREMENTS

To determine the Na_2CO_3 requirements, Chart 2:

Enter SO_2 emissions (lb/MM BTU) to be removed on item $\boxed{6}$ from page E-5, item $\boxed{5}$

Enter from the data sheets the maximum continuous input (MM BTU/hr) on item $\boxed{7}$

Connect items $\boxed{6}$ and $\boxed{7}$, extend to item $\boxed{8}$ and read and record:

SO_2 to be removed (lb/hr)______________ $\boxed{8}$

Connect item $\boxed{8}$ to pivot point $\boxed{9}$, extend to item $\boxed{10}$, read and record:

Na_2CO_3 requirements (lb/hr)____________ $\boxed{10}$

Enter weighed capacity factor from data sheet on item $\boxed{11}$

Connect items $\boxed{10}$ and $\boxed{11}$, extend to item $\boxed{12}$, read and record:

Na_2CO_3 requirements (ton/yr)__________ $\boxed{12}$

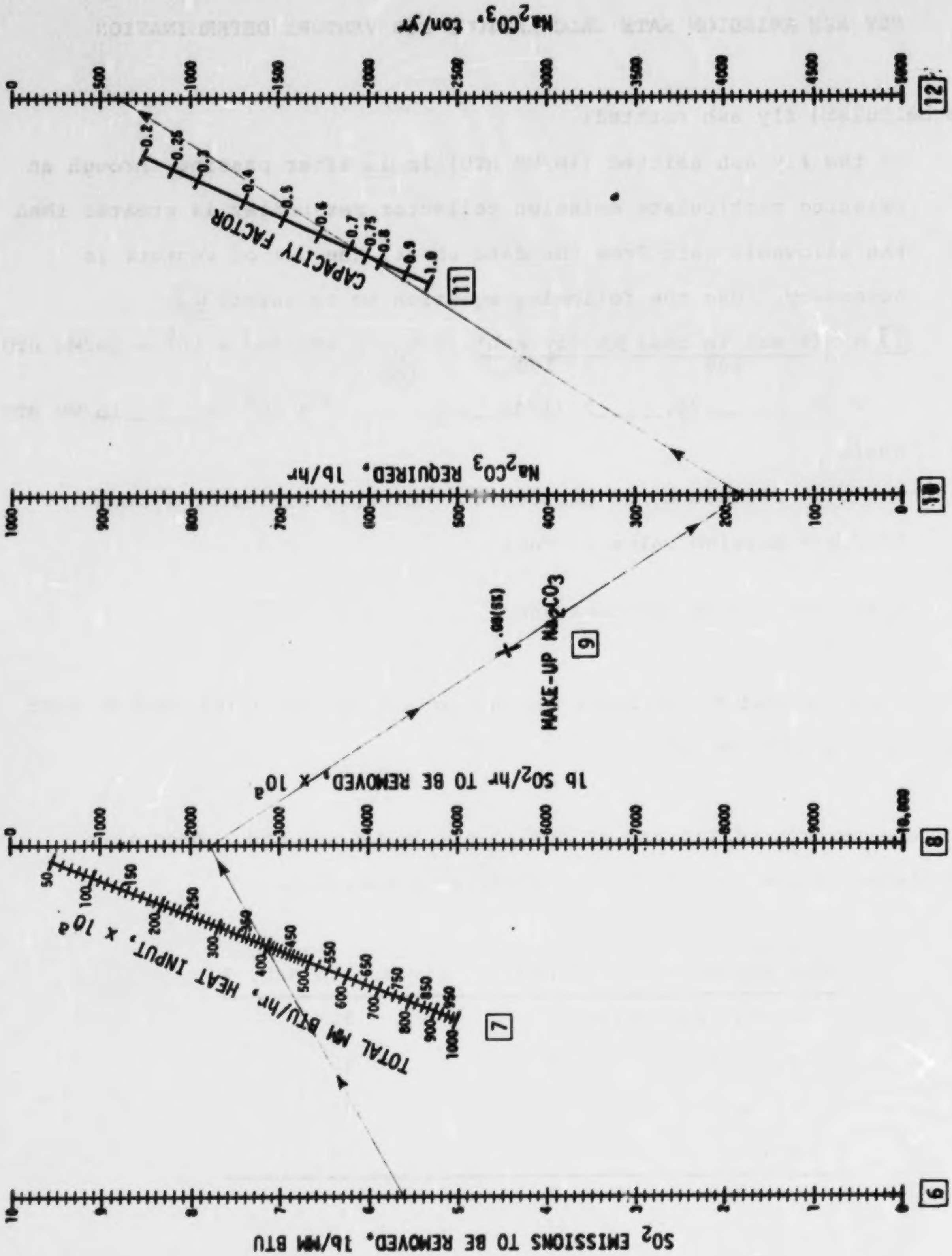


Chart 2. Na$_2$CO$_3$ REQUIREMENTS

FLY ASH EMISSION RATE CALCULATIONS FOR VENTURI DETERMINATION

To calculate fly ash emitted:

If the fly ash emitted (lb/MM BTU) in $\boxed{13}$ after passing through an existing particulate emission collector per boiler is greater than the allowable rate from the data sheet, the use of venturi is necessary. Use the following equation to calculate $\boxed{13}$

$$\boxed{13} = \left[\left(\frac{\%\text{ ash in coal}}{100}\right)\left(\frac{\%\text{ fly ash*}}{100}\right)\left(1-\frac{\eta_c}{100}\right) \div \text{BTU/lb}\right] \times 10^6 = \text{lb/MM BTU}$$

$$= \left[0.\_\_\_\_\_)(0.\_\_\_\_\_)\ (1-0.\_\_\_)\div\_\_\_\_\_\_\right] \times 10^6 = \_\_\_\_\_\text{lb/MM BTU}$$

where

η_c = Efficiency of particulate emission collector system

BTU/lb = Heating value of fuel

% fly ash = from the data sheet

If fly ash removal is required for any or all of the units VENTURI COST CALCULATIONS will be used.

*If the percent of fly ash to ash is not known use the appropriate tabulated values for the boiler under consideration.

Type boiler - coal-fired	fly ash to ash, %
General pulverized	80
Dry bottom	85
Wet bottom	65
Cyclone	10

VENTURI AND ABSORBER COSTS

To determine the costs of venturi and absorber (including demister) using Na_2CO_3 , Chart 3:

First, determine number of scrubber trains -

Enter acfm at °F of flue gas from the data sheet on $\boxed{14}$, either per boiler or combined plant total if °F is the same for all boilers.

Enter temperature of flue gas (°F) on $\boxed{15}$

Connect $\boxed{14}$ and $\boxed{15}$ and extend to $\boxed{16}$ and read flue gas acfm at 125°C (saturated) and enter________acfm at 125°F and sat. $\boxed{16}$

If acfm at 125°F is greater than 375,000 divide $\boxed{16}$ by a number less than 375,000 to give a whole number of venturis and/or absorbers for each boiler.

acfm per venturi and/or absorber ____________ $\boxed{17}$

$$\frac{\underline{\qquad\qquad}\,\boxed{16}}{\boxed{17}} = \underline{\qquad\qquad}\,\boxed{18}$$

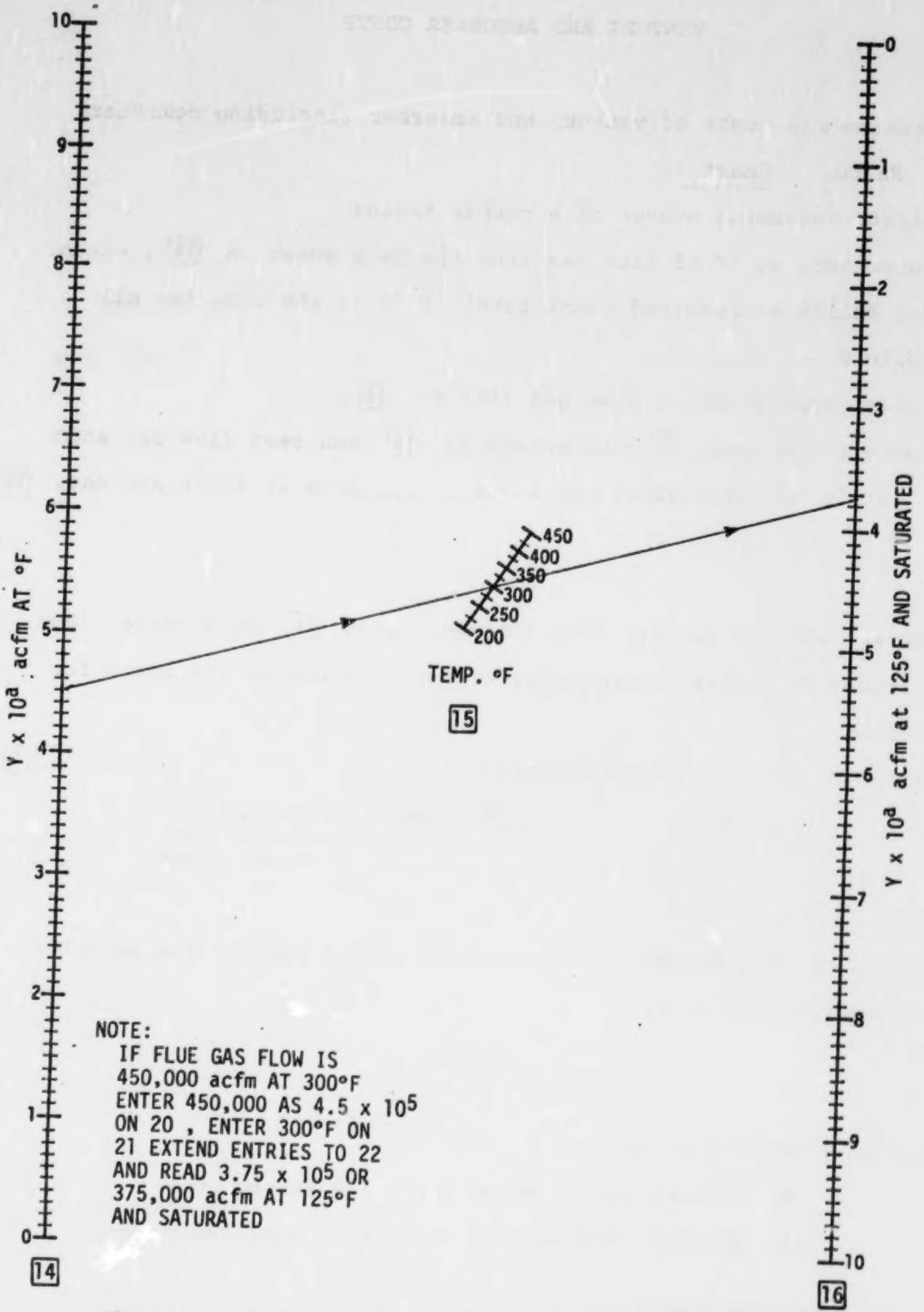
number of venturis
and/or absorbers per
boiler or power plant.

A venturi, or an absorber, or a combination of a venturi and absorber is sometimes called a train.

Assumptions: Costs are based on -

(a) Venturi throat velocity at 150 ft/sec

(b) Absorber velocity at 10 ft/sec, duel demisters



NOTE:
IF FLUE GAS FLOW IS
450,000 acfm AT 300°F
ENTER 450,000 AS 4.5 x 10^5
ON 20 , ENTER 300°F ON
21 EXTEND ENTRIES TO 22
AND READ 3.75 x 10^5 OR
375,000 acfm AT 125°F
AND SATURATED

Chart 3. acfm CORRECTED TO 125 °F AND SATURATED

VENTURI AND ABSORBER COSTS

Then determine absorber costs (no venturi required) Chart 4:

Enter item $\boxed{16}$ from page E-10, Chart 3 on Chart 4 on $\boxed{19}$

Enter for the absorber the cost factor of 2.05 on $\boxed{20}$

Connect $\boxed{19}$ and $\boxed{20}$ and extend to $\boxed{21}$ and read absorber cost

$ ________________ $\boxed{21}_A^*$

Or determine venturi costs (no absorber): Chart 5

Now enter item $\boxed{16}$ from page E-10, Chart 3 on Chart 4 on $\boxed{19}$

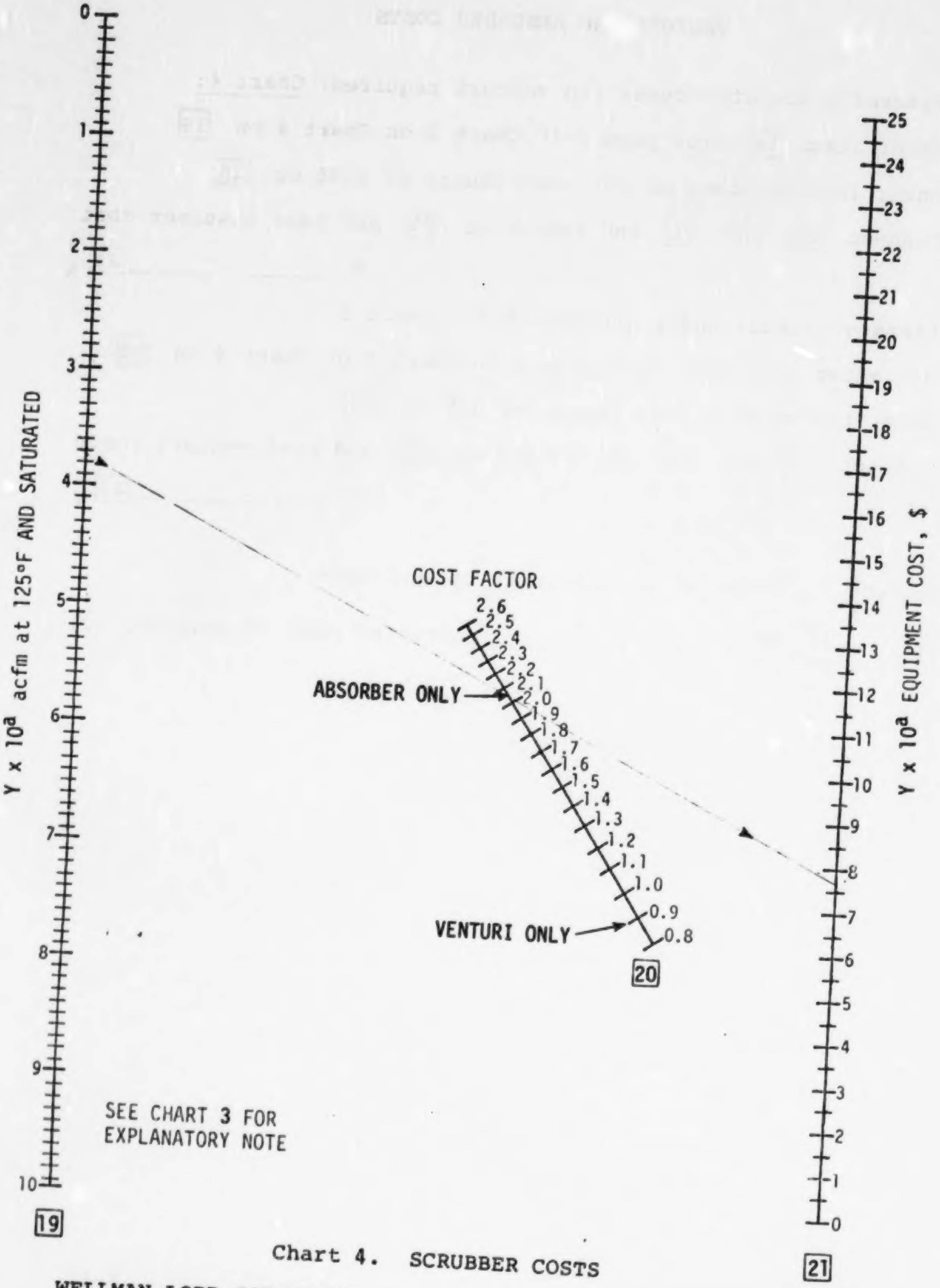
Enter the venturi cost factor of 0.9 on $\boxed{20}$

Connect $\boxed{19}$ and $\boxed{20}$ and extend to $\boxed{21}$ and read venturi costs

$ ________________ $\boxed{22}_V$

*To correct for velocity differential in absorber-

$\boxed{21}_A \times \frac{10\text{ fps}}{\_\_\_\text{fps}} = \$$ ________________ corrected cost of absorber $\boxed{21}_A$



SEE CHART 3 FOR
EXPLANATORY NOTE

Chart 4. SCRUBBER COSTS

WELLMAN-LORD SCRUBBING

VENTURI HOLDING TANK CAPACITY

If venturi is required, determine the holding tank capacity for venturi as follows:

Chart 5:

Enter flue gas acfm from page E-9, Chart 3, item $\boxed{16}$ on Chart 5, item $\boxed{23}$

Enter L/G* (liquid flow rate, gpm/1000 acfm at 125°F) on item $\boxed{24}$

Connect items $\boxed{23}$ and $\boxed{24}$, extend to item $\boxed{25}$, read and record:

Liquid flow rate (gal./min)______________ $\boxed{25}_V$ for venturi

Enter retention time** on item $\boxed{26}$

Connect item $\boxed{25}$ and $\boxed{26}$, extend to item $\boxed{27}$, read and record:

Tank capacity (gal.) per venturi______________ $\boxed{27}_V$

* if unknown, use 15.

** if unknown, use 4 min.

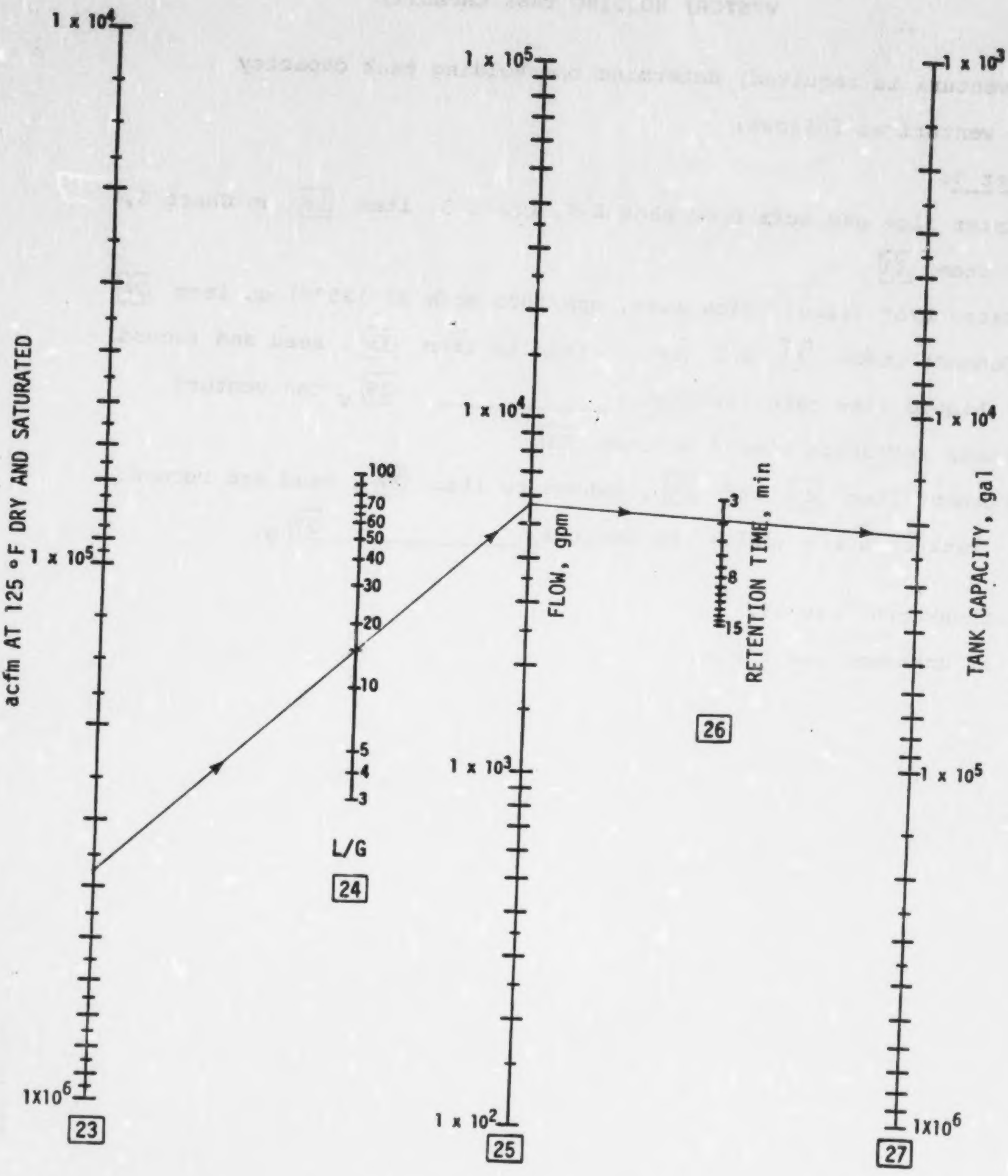


Chart 5. FLOW RATE AND TANK CAPACITY

WELLMAN-LORD SCRUBBING

VENTURI HOLDING TANK AGITATOR COSTS

To determine the cost of agitators per tank, Chart 6:

Compare tank capacity (gallons) from page E-13, Chart 5, item $\boxed{27}$ and/or $\boxed{27}_V$ on Table 6; under tank capacity in gallons column and record:

Cost of agitators per tank - $____________________ $\boxed{28}_V$

Total cost of venturi agitators:

($\boxed{28}_V$) x No. of venturis from page E-9, Chart 3, item $\boxed{18}$ = $\boxed{29}$

(____________) x ____________ = $__________________ $\boxed{29}$

AGITATOR COST

Table 6. AGITATOR COST

Tank capacity, gal.	Agitators	
	No.	28 y, cost, $
0 to 34,000	1	2,000
34,000 to 67,000	2	4,000
67,000 to 101,000	3	6,000
101,000 to 135,000	4	8,000
135,000 to 162,000	5	10,000
162,000 to 188,000	6	12,000
188,000 to 220,000	7	14,000
220,000 to 251,000	8	16,000
251,000 to 283,000	9	18,000

HOLDING TANK COSTS

To determine the tank cost the values in the chart are based on using \$12.50/ft^2 for a field-fabricated, rubber-lined tank, Chart 7:

Enter tank capacity (gallons) on item $\boxed{30}$ from page E-14, Chart 5, $\boxed{27}_V$, move vertically to item $\boxed{31}$

From item $\boxed{31}$ move horizontally to item $\boxed{32}$, read and record:

Tank cost per venturi \$______________ $\boxed{32}_V$

Total cost:

$\boxed{32}_V$ x No. of venturis from page E-9 = cost of holding tanks item $\boxed{18}$

___________ x ___________ = \$______________ $\boxed{33}$

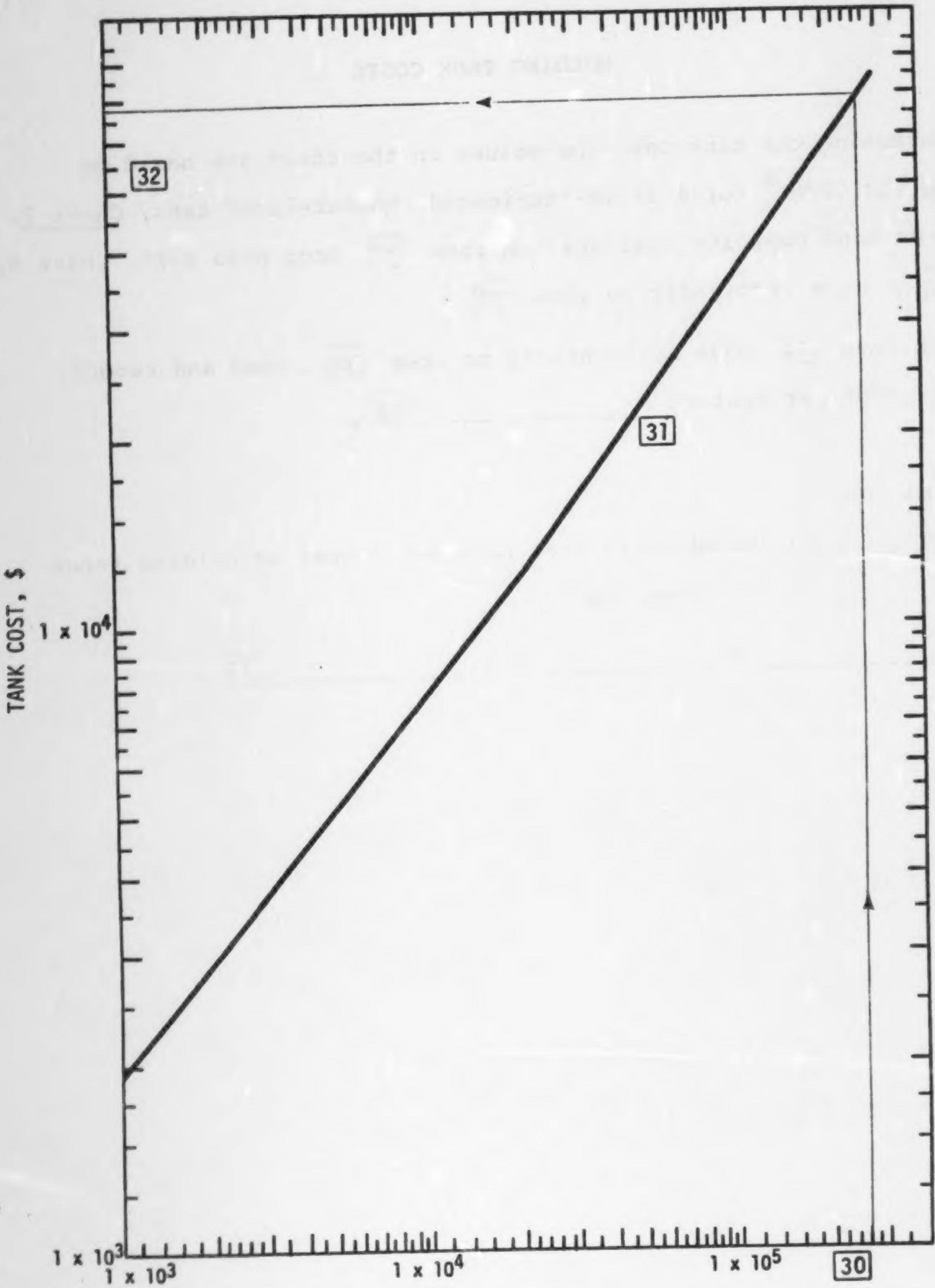


Chart 7. HOLDING TANK COSTS

VENTURI HOLDING TANK PUMP COSTS

Chart 8

From page E-10, Chart 3, item $\boxed{16}$ enter on item $\boxed{34}$ of chart 8

for venturi

Enter L/G of $\boxed{15}$ for the venturi on item $\boxed{35}$ on the venturi side

Connect items $\boxed{34}$ and $\boxed{35}$ and extend to item $\boxed{36}$

Connect item $\boxed{36}$ with hp vent., item $\boxed{37}$ and extend to item $\boxed{38}$

Connect item $\boxed{38}$ with $R_{venturi}$, item $\boxed{39}$ and extend to item $\boxed{40}$

Extend item $\boxed{40}$ horizontally to the right to item $\boxed{41}$ (cost per pump curve) and read cost ($) on the venturi side:

Unit No., boiler	;	Cost per pump $	x	Item 18		Include spare pump		Total pump cost-venturi, $	
	;		x		x	2	=		
	;		x		x	2	=		
	;		x		x	2	=		
	;		x		x	2	=		
	;		x		x	2	=		
	;		x		x	2	=		
	;		x		x	2	=		
	;		x		x	2	=		
	;		x		x	2	=		
	;		x		x	2	=		
Combined	;		x		x	2	=		$\Sigma\ \boxed{41}_{V}$

Total cost $______________ $\Sigma\ \boxed{41}_{V}$

Follow the same procedure for absorber pump cost and note absorber pumps total cost = $ __________ $\Sigma\ 41_{A}$

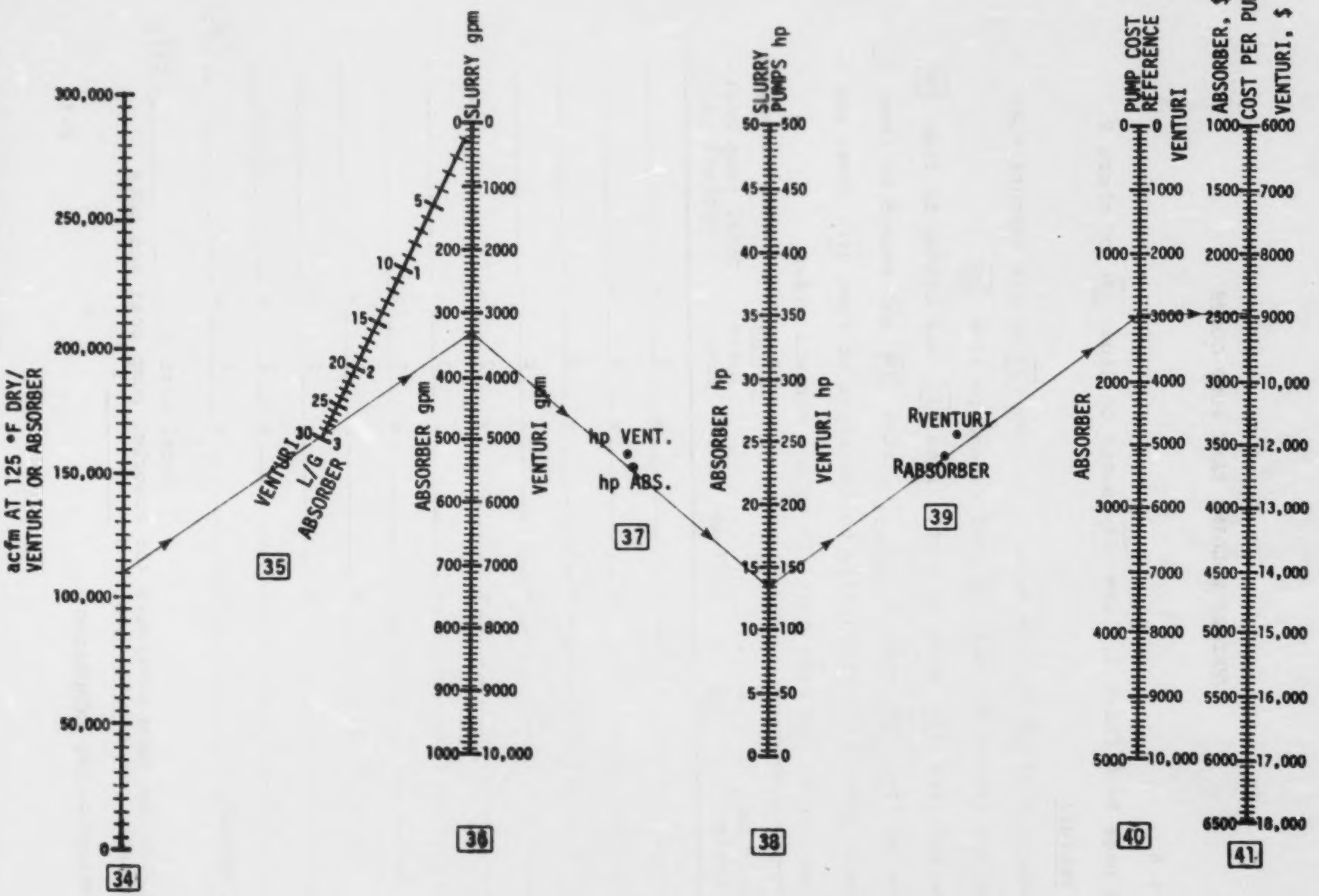


Chart 8. HOLDING TANK PUMP COST

FAN COSTS

To determine fan costs, Chart 9 :

Enter acfm at °F of flue gas from the data sheet on [42]

Select appropriate curve for pressure drop* on [43]

Move vertically from [42] to [43] and then from [43] horizontally to [44] read and record:

Fan costs $____________ [44]

* Typical pressure drop: Absorber 21" (including 3" safety)
absorber and venturi 30" (including 3" safety)

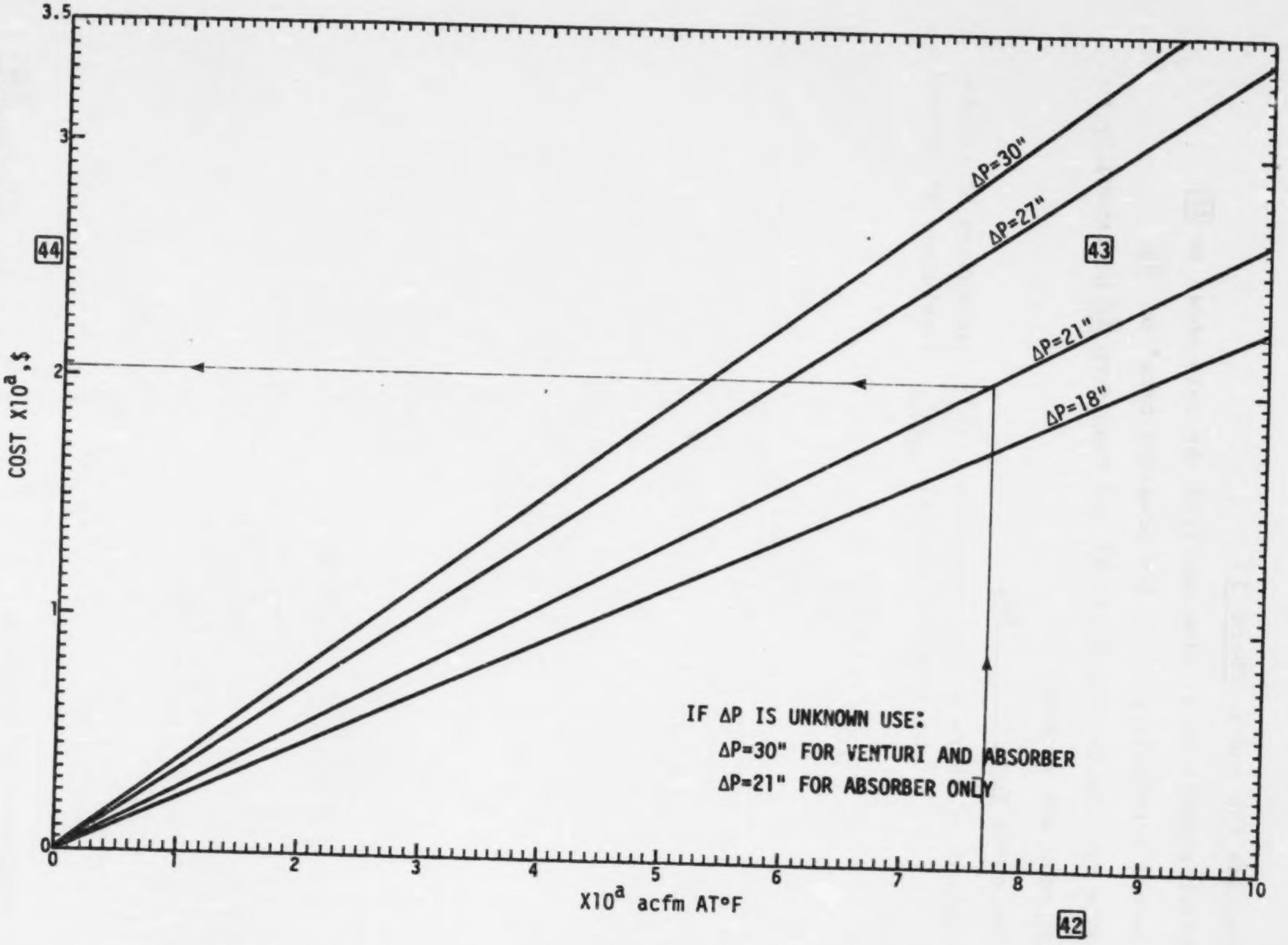


Chart 9. FAN COST

HEAT EXCHANGER COST

To determine heat exchanger cost, Chart 10:

Enter item $\boxed{16}$ from page E-10,Chart 3, on Chart 10, item $\boxed{45}$

Move vertically upward to item $\boxed{55}$ for $\Delta T = 50^\circ F$, if another ΔT is used record______°F

From $\boxed{55}$ move horizontally to the left to $\boxed{56}$, read and record:

Cost for heat exchangers $________________ $\boxed{56}$

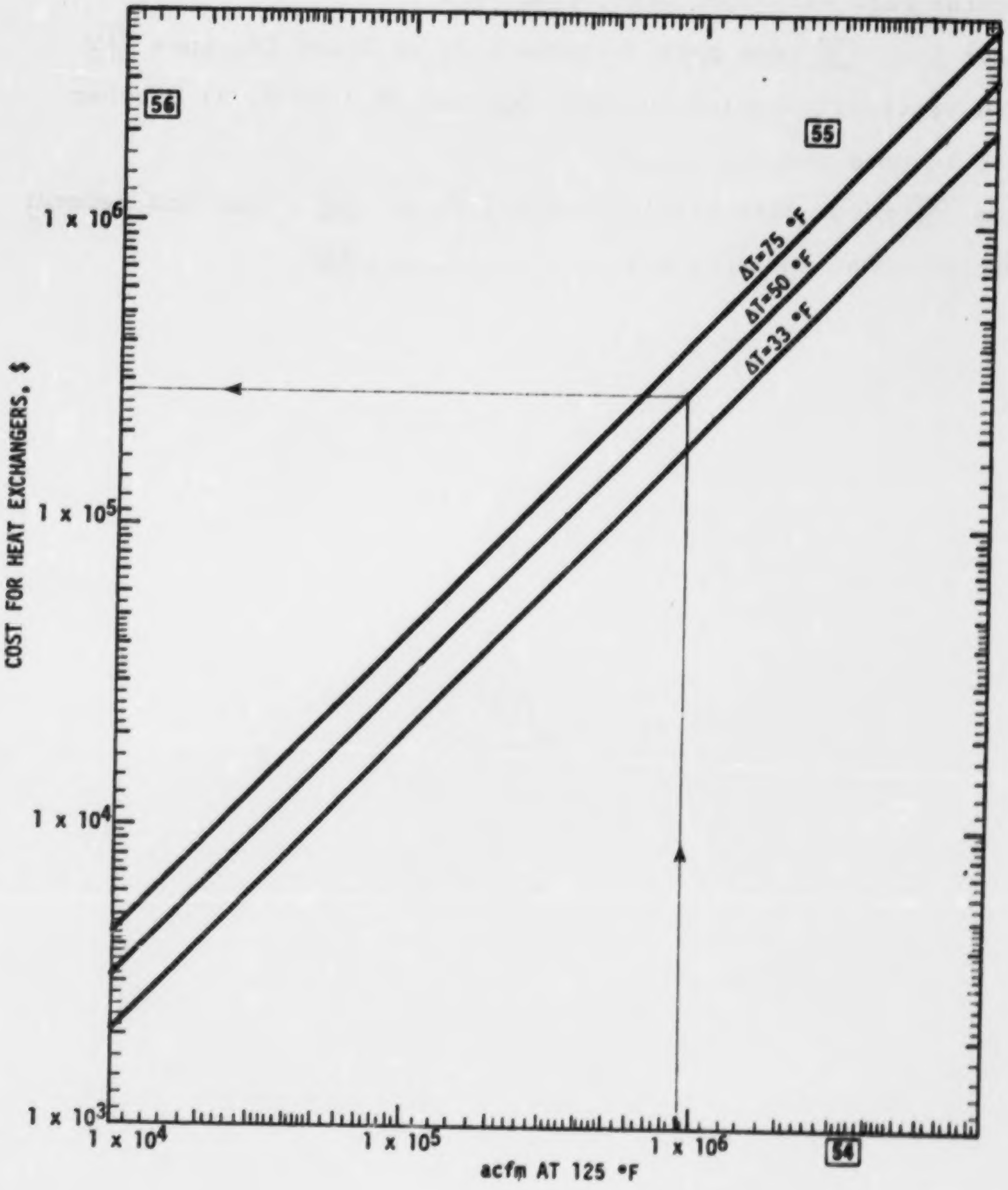


Chart 10. HEAT EXCHANGER COSTS

SOOT BLOWER COST

To determine soot blower cost, Chart 11:

Enter item $\boxed{17}$ from page E-9, Chart 3 on Chart 11, item $\boxed{57}$

Move vertically upward to $\boxed{58}$

From $\boxed{58}$ move horizontally to the left to $\boxed{59}$ and read:

Cost per train . \$______________ $\boxed{59}$

Record from page E-9, Chart 3, item $\boxed{18}$__________, number of trains

Cost of soot blowers:

$\boxed{59}$ x $\boxed{18}$ = $\boxed{60}$

\$______________ x ______________ = \$______________ $\boxed{60}$

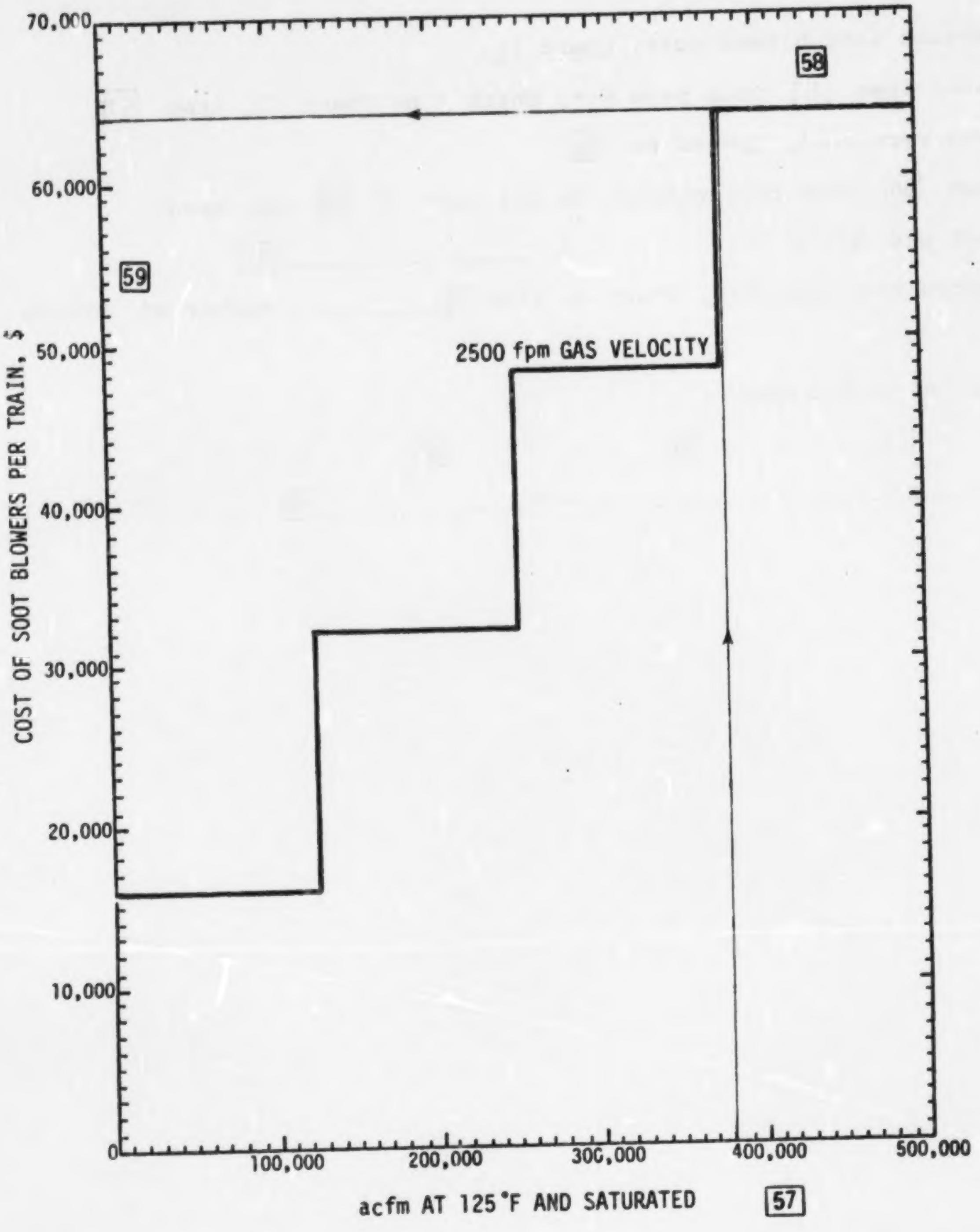


Chart 11. SOOT BLOWER COSTS

REHEAT COST

To calculate the cost of reheat, Chart 12:

Enter acfm at 125°F and saturated of the flue gas from page E-10 Chart 3, item $\boxed{16}$ on Chart 12, item $\boxed{61}$

Select and enter ΔT* on item $\boxed{62}$

* if unknown, use 50°

Connect items $\boxed{61}$ and $\boxed{62}$ and extend to item $\boxed{63}$ record

Enter costs ($/MM BTU) reheat* from calculation below on item $\boxed{64}$

Connect items $\boxed{63}$ and $\boxed{64}$ and extend to item $\boxed{65}$, read and record:

Cost ($/hr) reheat ______________________ $\boxed{65}$

Annual reheat cost:

$$\underset{\boxed{65}}{\$\underline{\hspace{3cm}}} \times 8760 \text{ hr/yr} \times \underset{\text{Weighted capacity factor from data sheet}}{0.\underline{\hspace{3cm}}} = \underset{\text{reheat cost/yr}}{\$\underline{\hspace{3cm}}}\ \boxed{66}$$

*Reheat Cost -

Coal: To correct from 12,000 BTU/lb and $10/ton

$$= 665 \times \frac{\underline{\hspace{2cm}}(\$/\text{ton})}{\underline{\hspace{2cm}}\text{BTU/lb}}$$

= $______________________/MM BTU

Oil: To correct from 149,000 BTU/gal. and $10/bbl

$$= 31{,}707 \times \frac{\underline{\hspace{2cm}}(\$/\text{bbl})}{\underline{\hspace{2cm}}\text{BTU/gal.}}$$

= $______________________/MM BTU

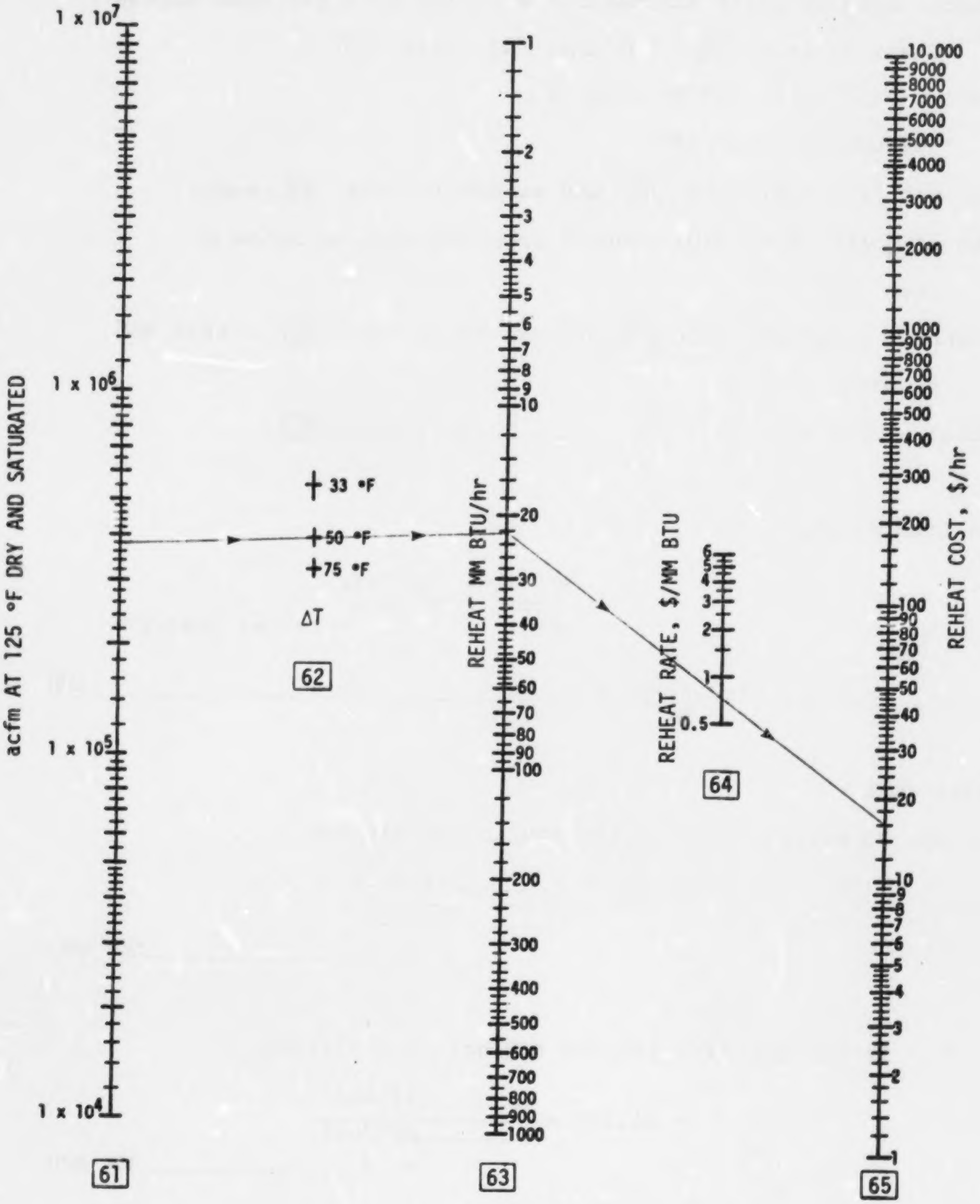


Chart 12. REHEAT COSTS

DUCT COSTS

To calculate ducting cost:

Assumption-

The length of flue duct from the main discharge duct to the venturi (if used) is variable in feet and also the return to the main discharge duct after SO_2 and/or particulate removal. For the specific boiler if more than 1 venturi and/or absorber is required use the multipliers listed in Table 13. Compute each boiler separately, unless identical to each other in absorber or venturi acfm at 125°F and saturated.

From data sheet,
acfm at °F

Area duct (from main) in: $\dfrac{\_\_\_\_\_\_\_\_}{3{,}500\ \text{ft/min}} = \_\_\_\_\_\_\_\_\ \text{ft}^2 = 2\lambda^2$

Perimeter length:

$$\lambda^2 = \frac{\_\_\_\_\_\_\_\_}{2} = \_\_\_\_\_\_\_\_\ \text{ft}^2$$

$$\lambda = \sqrt{\_\_\_\_\_\_\_\_\ \text{ft}^2} = \_\_\_\_\_\_\_\_\ \text{ft}$$

$$6\lambda = 6\text{x}\ \_\_\_\_\_\_\_\_\ \text{ft} = \_\_\_\_\_\_\_\_\ \text{ft perimeter}$$

Cost: ________ ft perimeter x 18 lb/linear ft x \$0.39/lb =
7.02 x ________ ft perimeter = \$____ cost/linear ft $\boxed{67}$

Page E-10, Chart
3, item $\boxed{16}$

Area duct (to main) out: $\dfrac{\_\_\_\_\_\_\_\_}{2{,}500\ \text{ft/min}} = \_\_\_\_\_\_\_\_\ \text{ft}^2 = 2\lambda^2$

Perimeter length:

$$\lambda = \sqrt{\frac{\_\_\_\_\ \text{ft}^2}{2}} = \_\_\_\_\_\_\_\_\ \text{ft}$$

$$6\lambda = 6 \text{ x}\ \_\_\_\_\_\_\_\_\ \text{ft} = \_\_\_\_\_\_\_\_\ \text{ft perimeter}$$

Cost: ________ ft perimeter x 18 lb/linear ft x \$0.445/lb =
8.01 x ________ ft perimeter = \$________ cost/linear ft $\boxed{68}$

DUCT COST

Table 13. MULTIPLIER FOR DUCT COST

No. of absorbers and/or venturis per boiler	Venturi and absorber in	Venturi or absorber only in	Venturi plus absorber out	Venturi or absorber only out
1	110	70	70	50
2	190	114	113	93
3	250	180	143	123
4	305	225	175	155
5	356	266	205	183
6	410	310	235	208
7	453	346	262	242
8	490	378	288	268
9	535	415	315	295
10	579	452	343	324

* Duct cost in -

(in) cost/linear ft x (Table 13 multiplier + Estimated ft to main duct-(30')) = Duct cost (in) 69

67 $________ x (________ + ________ -30) = $________ 69

**Duct cost out -

(out) cost/linear ft x (Table 13 multiplier + Estimated distance to main duct -(50')) = Duct cost (out) 70

68 $________ x (________)+(________ -50) = $________ 70

Total duct cost -

69 duct cost (in) + 70 duct cost (out) = total duct cost 71

$________ + $________ = $________ 71

---

* If congested area add 230 ft for estimated ft.

** If congested area add 200 ft for estimated ft.

FLUE GAS SHUTOFF AND BYPASS VALVES

To calculate flue gas shutoff and bypass valve costs:

Assumption-

Based on 4 vanes/axis in short dimension based on height of 20 ft and width of 10 ft,
Stainless steel at $141.6/ft^2; carbon steel at $99.1/ft^2

Flue gas valve (in) at main duct to create a bypass

$$\frac{\text{From the data sheet acfm at } \underline{\hspace{1cm}}\,{}^\circ\text{F}}{3{,}500} \Big/ \text{Boiler} = \underline{\hspace{2cm}}\ \text{ft}^2 = 2\text{W}^2$$

$$\text{W} = \sqrt{\frac{\underline{\hspace{2cm}}}{2}\ \text{ft}^2};\ \text{W} \times 2 = \underline{\hspace{1.5cm}} \times 2 = \text{height, ft}$$

$$\text{Valve cost A} = (1.5 \times \text{H})\ \left[(99.1) \pm^{*} (3.1)\ (\text{H}-20)\ (0.5\text{H}-10)\right]$$

*H greater than 20 ft, sign is +, less than 20 ft sign is -

$$= (1.5 \times \overset{(\text{H})}{\underline{\hspace{1cm}}})\ \left[(99.1) \pm (3.1)\ (\overset{(\text{H})}{\underline{\hspace{1cm}}}-20)\ (0.5\overset{(\text{H})}{\underline{\hspace{1cm}}}-10)\right]$$

$$= \$\underline{\hspace{3cm}}\ \text{carbon steel} \quad \boxed{72}$$

Flue gas valve (out) at main duct to create a bypass

$$\frac{\text{Page E-10, Chart 3 item } \boxed{16} \text{ acfm at } \underline{\hspace{1cm}}\,{}^\circ\text{F}}{2{,}500} \Big/ \text{Boiler} = \frac{\text{Chart 3 Item } \boxed{16}}{2{,}500} = \underline{\hspace{2cm}}\ \text{ft}^2 = 2\text{W}^2$$

$$\text{W} = \sqrt{\frac{\underline{\hspace{2cm}}}{2}\ \text{ft}^2};\ \text{W} \times 2 = \underline{\hspace{1.5cm}} \times 2 = \underline{\hspace{1.5cm}}\ \text{ft (height H)}$$

$$\text{Valve cost B} = (1.5 \times \overset{(\text{H})}{\underline{\hspace{1cm}}})\ \left[(141.6) \pm^{*} (4.5)\ (\overset{(\text{H})}{\underline{\hspace{1cm}}}-20)\ (0.5\overset{(\text{H})}{\underline{\hspace{1cm}}}-10)\right]$$

$$= \underline{\hspace{3cm}}\ \text{stainless steel} \quad \boxed{73}$$

Flue gas valve (in) to absorber and/or venturi train

$$\frac{\text{From data acfm at } \underline{\hspace{1cm}}\,{}^\circ\text{F} \big/ \text{Boiler}}{(\boxed{18}\ \text{No. of venturis or absorbers}) \times 3{,}500} = \text{Area, ft}^2$$

FLUE GAS SHUTOFF AND BYPASS VALVES (continued)

$$\frac{\_\_\_\_\_\_\_\_\_\_\_\_}{\boxed{18}\,\_\_\_\_\_\_\_\_ \times 3{,}500} = \_\_\_\_\_\_\_\_\_\_\_\_ = \text{Area, ft}^2 = 2W^2$$

$$W = \sqrt{\frac{\_\_\_\_\_\_}{2}}\ \text{ft}^2;\quad W \times 2 = \_\_\_\_\_\_\_\_\_\_\_\_\ \text{Height (H), ft}$$

Valve cost C

$$= (\text{Height (H)} \pm 0.5\ \text{Height (H)})\left[(99.1)-(3.1)(H-20)\ (0.5H-10)\right]$$

$$= (1.5 \times \overset{(H)}{\_\_\_\_})\ \left[(99.1)-(3.1)\ (\overset{(H)}{\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_}-10)\right]$$

$$= \_\_\_\_\_\_\_\_\_\_\_\_\ \text{carbon steel} \qquad \boxed{74}$$

Valve cost D =

$$\left(\begin{matrix}\text{Page E-9, item 18}\\ \text{No. of venturis and/or absorbers}\end{matrix}\right) \times (\text{valve cost}_C\ \boxed{74}) = \qquad \boxed{75}$$

$$= (\_\_\_\_\_\_\_\_) \times (\_\_\_\_\_\_\_\_\_\_) = \$\_\_\_\_\_\_\_\_\_\_\_\_\ \boxed{75}$$

Flue gas valve (out) from absorber and/or venturi

$$\frac{\text{Page E-9, item 17}}{\frac{1.08\ \text{acfm at } 175°\text{F}}{2{,}500}} \Big/ \text{Venturi and/or absorber} = \text{ft}^2$$

$$\boxed{17}$$

$$0.000432 \times \_\_\_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_\_\_\ \text{ft}^2 = 2W^2$$

$$W = \sqrt{\frac{\_\_\_\_\_\_}{2}}\ \text{ft}^2;\quad W \times 2\,\_\_\_\_\_\_\ \times 2 = \_\_\_\_\_\_\_\_\_\_\ \text{ft, (H)}$$

Valve cost_E =

$$= (1.5\overset{(H)}{\_\_\_\_\_\_})\ \left[(141.6)-(4.5)\ (\overset{(H)}{\_\_\_\_\_\_}-20)\ (0.5\overset{(H)}{\_\_\_\_\_\_}-10)\right]$$

$$= \$\_\_\_\_\_\_\_\_\_\_\_\_\_\_\ \text{stainless steel}\ \boxed{76}$$

Valve cost_F =

$$\left(\begin{matrix}\text{Page E-9, item 18}\\ \text{No. of venturis and/or absorbers}\end{matrix}\right) \times (\text{valve cost}_E\ \boxed{76}) = \qquad \boxed{77}$$

$$= (\_\_\_\_\_\_\_\_) \times (\_\_\_\_\_\_\_\_\_\_) = \$\_\_\_\_\_\_\_\_\_\_\ \boxed{77}$$

Valving cost per boiler

$$\text{Valve cost}_G = \boxed{72} + \boxed{73} + \boxed{75} + \boxed{77} = \boxed{78}$$

$$= \quad V_A \qquad V_B \qquad V_D \qquad V_F$$

$$= \_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_$$

$$= \$\_\_\_\_\_\_\_\_\_\_\_\_\ \text{total valve cost} \qquad \boxed{78}$$

ABSORBER FEED SURGE TANK AND SULFITE STORAGE TANK COSTS

From page E-7, item $\boxed{8}$ Chart 2, record lb SO_2/hr ______________;

______________lb SO_2/hr x 25.4 = ______________gal. Na_2SO_3 $\boxed{79}$

24 hr, 25% slurry storage

Enter gallons Na_2SO_3 item $\boxed{79}$ on Chart 7, item $\boxed{30}$ and move vertically upward to intersect the curve, item $\boxed{31}$ then move horizontally to the left item $\boxed{32}$ read and record:

$____________ x 2 = $______________ tank cost $\boxed{80}$

AGITATOR COSTS FOR ABSORBER FEED SURGE AND SULFITE STORAGE TANKS

From page E-32, item $\boxed{79}$ enter gallons* at appropriate level on
Chart 6 and read number of agitators required per tank
__________ and read agitator cost: $______________ $\boxed{81}$

*(If capacity required is greater than 283,000 gal., divide capacity by 283,000 =

Capacity, gal.
______________=_______number of tanks required
283,000

If a decimal number appears raise to the next highest whole number. Divide capacity (gallons) by highest whole number

Capacity, gal.
______________=_________capacity gallons per tank
____(whole No.)

Enter this capacity (gallons) on Table 6 to determine agitators per tank required above)

whole number of tanks	x	Table 6 Cost of agitators/ tank, $	x	Absorber feed surge and sulfite tanks	=	Agitator costs, $
__________	x	______________	x	2	=	______________ $\boxed{81}$

STORAGE SILO COSTS

Chart 14

From page E-7, Chart 2, item $\boxed{8}$ recorded, enter this on Chart 14 item $\boxed{82}$ and move horizontally to item $\boxed{83}$

Record ______________ $\boxed{83}$ tons Na_2CO_3 required.

Enter item $\boxed{83}$ on item $\boxed{84}$ and determine largest silo or number of silos by keeping the number of silos to a minimum and enter whole number by connecting item $\boxed{84}$ to item $\boxed{85}$ (tons/silo selected) connect and extend items $\boxed{84}$ and $\boxed{85}$ to item $\boxed{86}$ and read:

___________ $\boxed{86}$ No. of silos; _______ $\boxed{85}$ tons/silo (use larger recorded number on chart)

Enter selected $\boxed{85}$ on $\boxed{87}$

Connect items $\boxed{86}$ and $\boxed{87}$ and extend to item $\boxed{88}$ and read:

Total Silo cost $____________ $\boxed{88}$

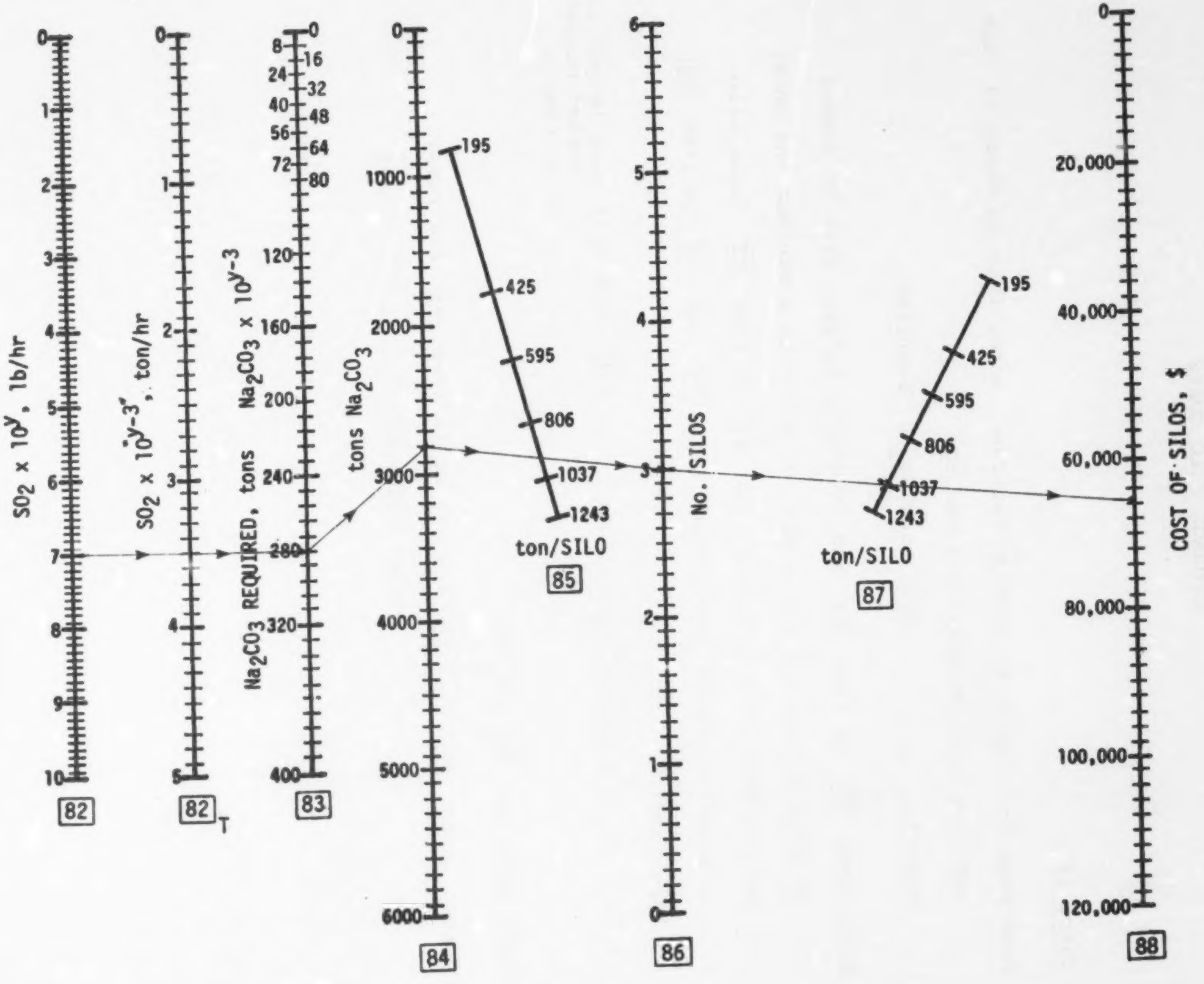


Chart 14. STORAGE SILO COSTS

VIBRATOR FEEDER COSTS

From page E-35, Chart 14 enter item $\boxed{83}$ below and divide bv 720 to procure ton/hr Na_2CO_3 makeup required and then add cost factor for feeder $\boxed{\text{FD}}$

From page E-35, Chart 14 multiply item $\boxed{86}$ for total feeder costs

$$\left[\frac{\boxed{\text{FD}}}{1875} + \left(\begin{array}{l}\text{Chart 14}\\ \text{Item } \boxed{83}\end{array} \times \frac{1}{720}\right)\right] \times \begin{array}{l}\text{Chart 14}\\ \text{Item } \boxed{86}\end{array}$$

$$\left[\underline{\qquad} + \left(\underline{\qquad\qquad\qquad} \times \frac{1}{720}\right)\right] \times \underline{\qquad\qquad} = \$\underline{\qquad\qquad}\text{Total feeder costs } \boxed{89}$$

DISSOLVING TANK AND AGITATOR COSTS

Chart 15

From page E-7, Chart 2, item $\boxed{8}$, enter this on item $\boxed{90}$ and move vertically upward to item $\boxed{92}$.

Then move horizontally to item $\boxed{93}$ and read tank and agitator costs:

$____________ cost of dissolving tank and agitator $\boxed{93}$

Pump costs and gpm:

From page E-7, Chart 2, item $\boxed{8}$, enter this on item $\boxed{90}$ and move vertically upward to items $\boxed{91}$ and $\boxed{94}$.

Then move horizontally to items $\boxed{95}$ and $\boxed{93}$ and read pump cost and gpm:

$____________ cost of pump $\boxed{93}_{P}$

____________ gpm $\boxed{95}$

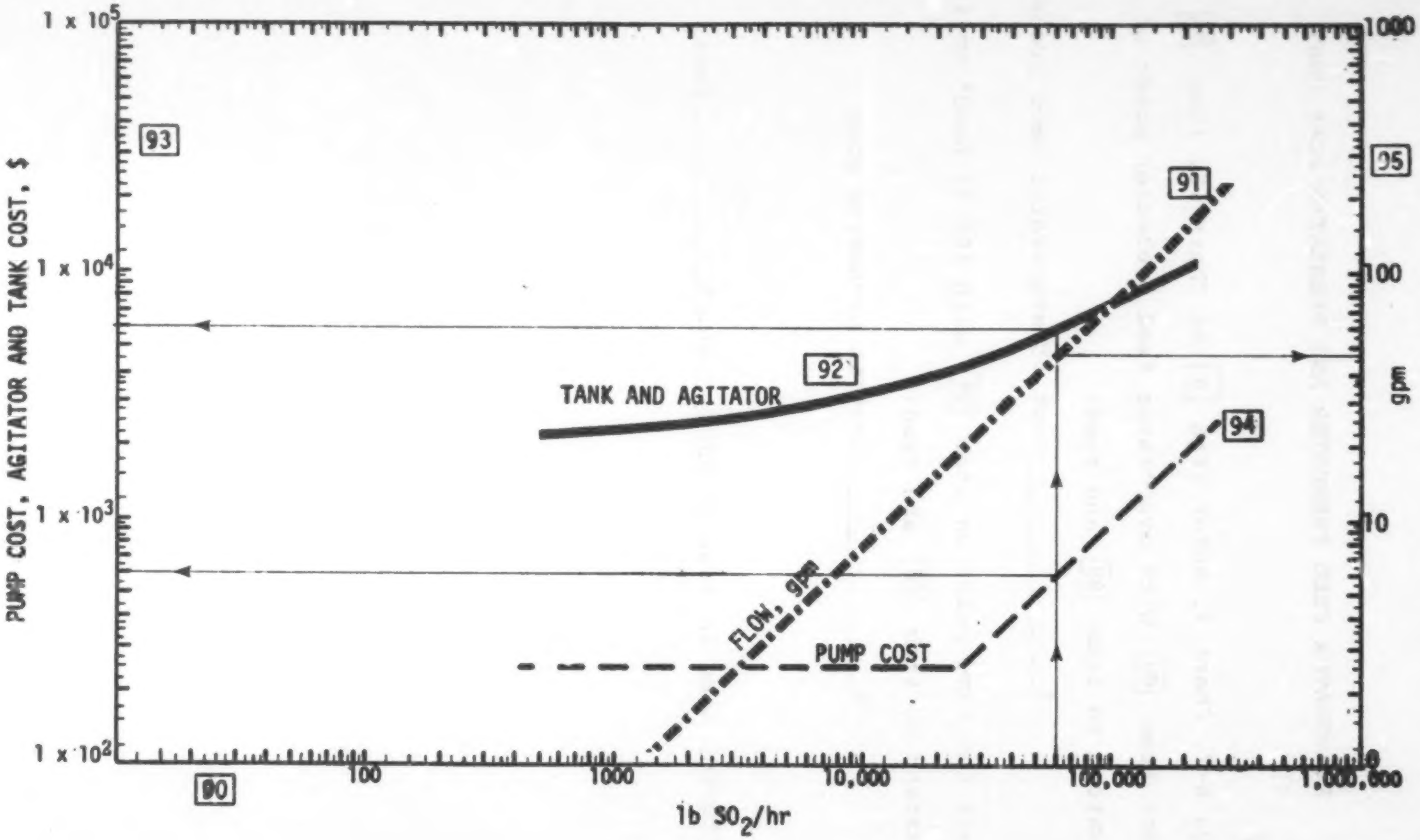


Chart 15. DISSOLVING TANK AND AGITATOR COSTS

EVAPORATOR FEED PREHEATER AND PREHEATER PUMP COST

Chart 16

From page E-7, Chart 2, enter item $\boxed{8}$ on Chart 16, item $\boxed{96}$

Connect item $\boxed{96}$ with evaporator feed preheater point on item $\boxed{97}$ and extend to item $\boxed{98}$ and read:

$______________cost of evaporator feed preheater $\boxed{98}_H$

Connect the same point on item $\boxed{96}$ with 100 ft head* on item $\boxed{97}$ and extend to item $\boxed{98}$ and read:

$______________cost of preheater pump $\boxed{98}_P$

* If different head in feet is used, record___________feet.

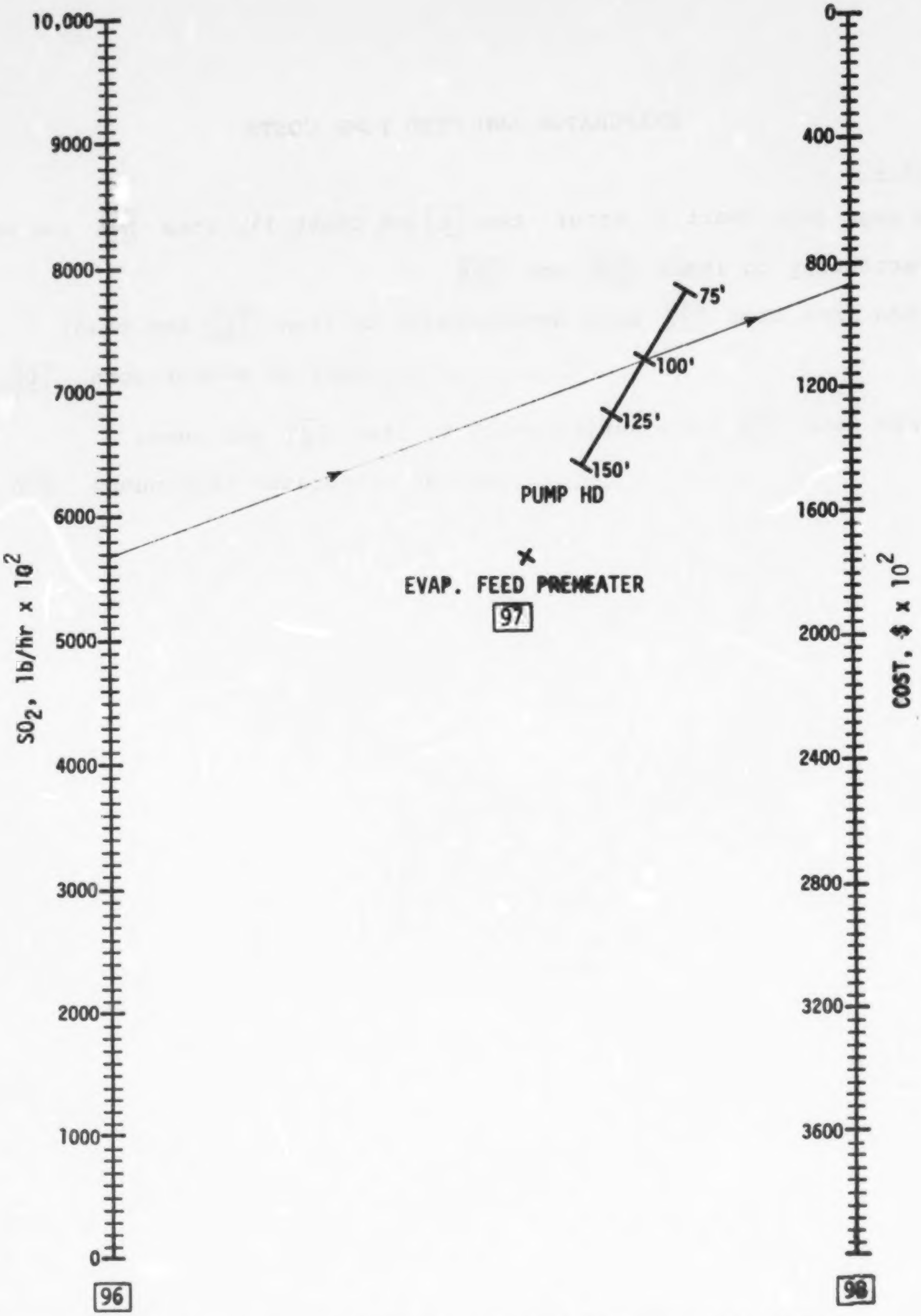


Chart 16. EVAPORATOR FEED PREHEATER AND PREHEATER PUMP COSTS

EVAPORATOR AND FEED PUMP COSTS

Chart 17

From page E-7, Chart 2, enter item $\boxed{8}$ on Chart 17, item $\boxed{99}$ and move vertically to items $\boxed{100}$ and $\boxed{101}$

Then from item $\boxed{100}$ move horizontally to item $\boxed{102}$ and read:

$________________cost of evaporators $\boxed{102}_{EV}$

From item $\boxed{101}$ move horizontally to item $\boxed{102}$ and read:

$________________cost of evaporator feed pumps $\boxed{102}_{P}$

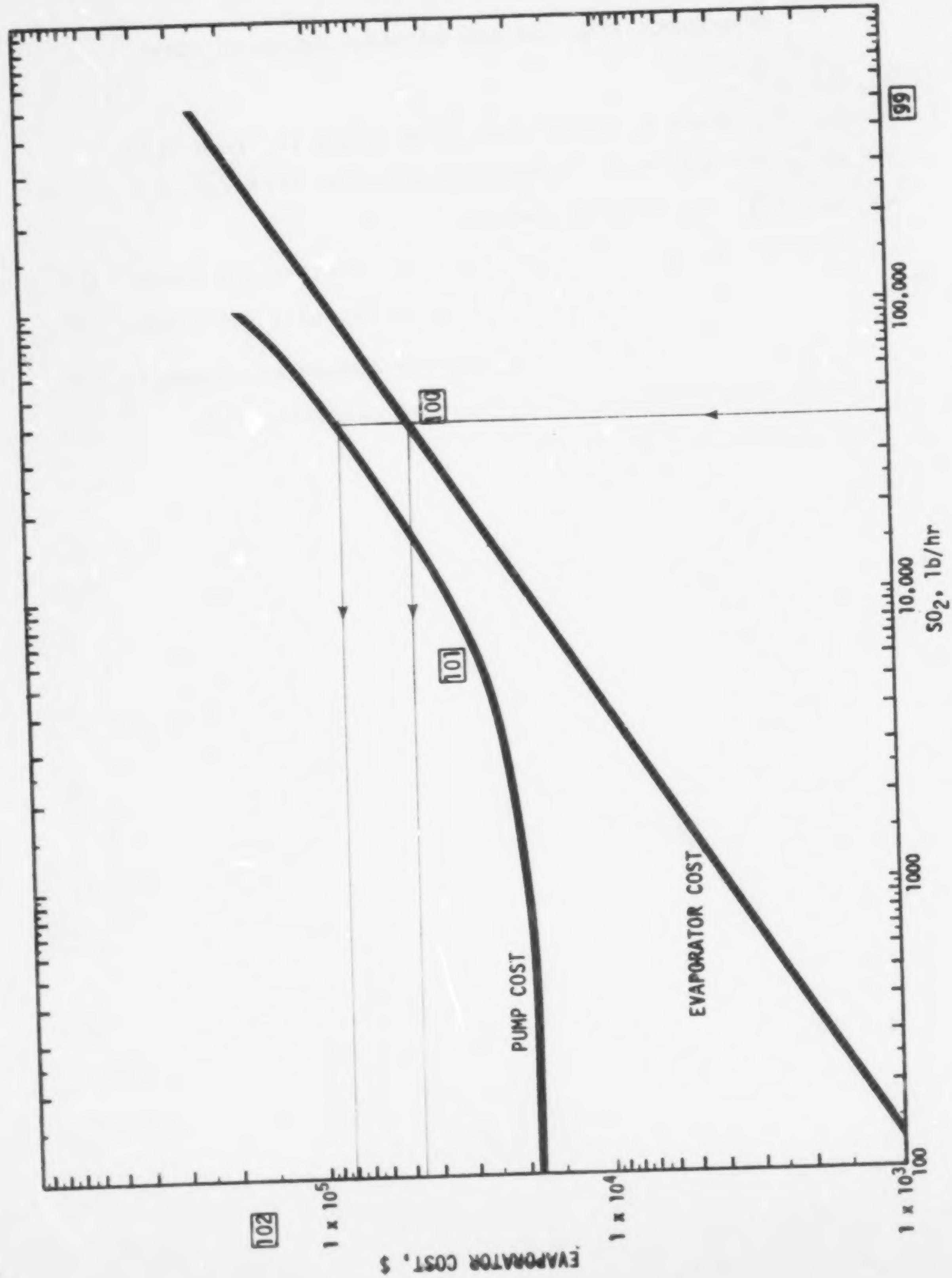


Chart 17. EVAPORATOR AND FEED PUMP COSTS

EVAPORATOR REBOILER AND PRIMARY CONDENSER COSTS

Chart 18

From page E-7, Chart 2, enter item $\boxed{8}$ on Chart 18, item $\boxed{103}$

Connect item $\boxed{103}$ with appropriate point on item $\boxed{104}$ and extend to item $\boxed{105}$ and read and record:

\$________________cost of reboiler 1st stage $\boxed{105}_{E1}$

\$________________cost of reboiler 2nd stage $\boxed{105}_{E2}$

\$________________cost of condenser, primary $\boxed{105}_{C}$

\$________________cost of condenser, SO_2 $\boxed{105}_{SO_2}$

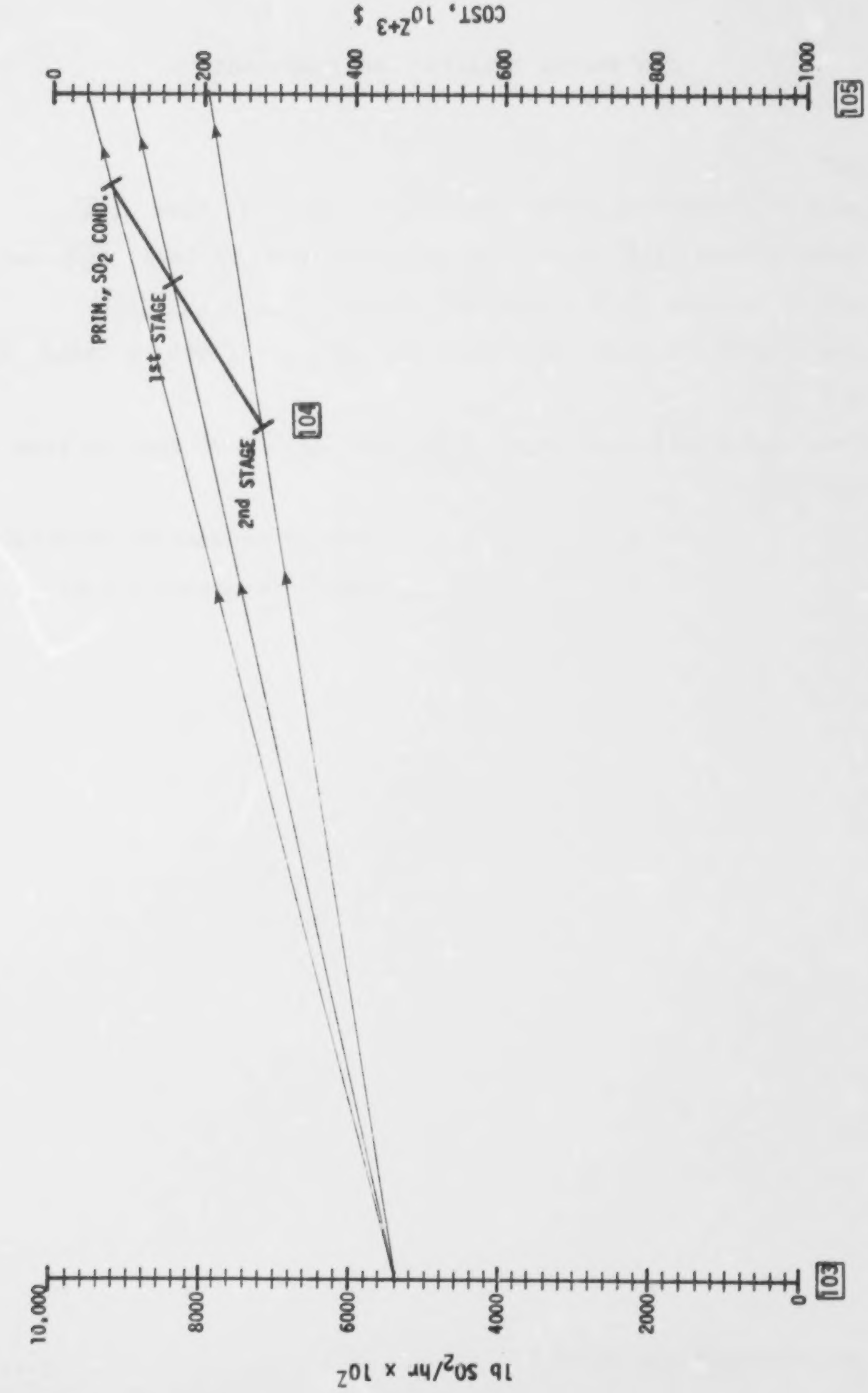


Chart 18. EVAPORATOR REBOILER AND PRIMARY CONDENSER COSTS

CONDENSATE RECEIVER AND PUMP COSTS

Chart 19

From page E-7, Chart 2, enter item $\boxed{8}$ on Chart 19, item $\boxed{106}$

Connect item $\boxed{106}$ with 2-hr retention time on item $\boxed{107}$ and extend to item $\boxed{108}$. Read and record ____________ $\boxed{108}$

Enter $\boxed{108}$ on item $\boxed{109}$ move horizontally right to items $\boxed{110}$ and $\boxed{111}$

From these points on items $\boxed{110}$ and $\boxed{111}$ move down to item $\boxed{112}$ and read:

$______________ cost of condensate receivers $\boxed{112}_R$

$______________ cost of condensate pump $\boxed{112}_P$

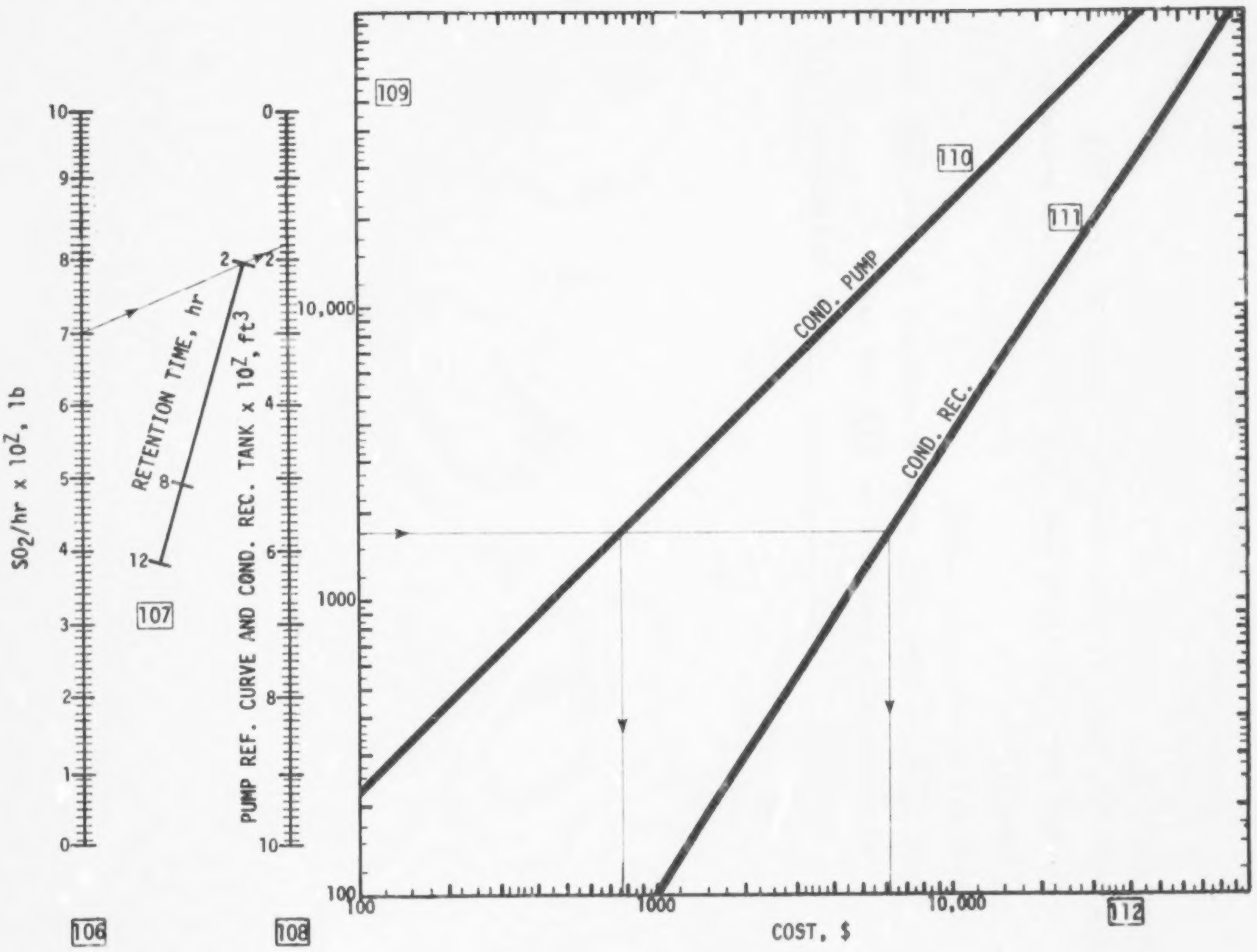


Chart 19. CONDENSATE RECEIVER AND PUMP COSTS

STRIPPER COSTS

Chart 20

From page E-7, Chart 2, enter item $\boxed{8}$ on Chart 20, item $\boxed{113}$

Connect item $\boxed{113}$ with item $\boxed{114}$ pivot point and extend to item $\boxed{115}$

Read and record__________ $\boxed{115}$

Enter $\boxed{115}$ on item $\boxed{116}$ move horizontally to item $\boxed{117}$ then move vertically down to item $\boxed{118}$ and read:

$____________________cost of stripper $\boxed{118}$

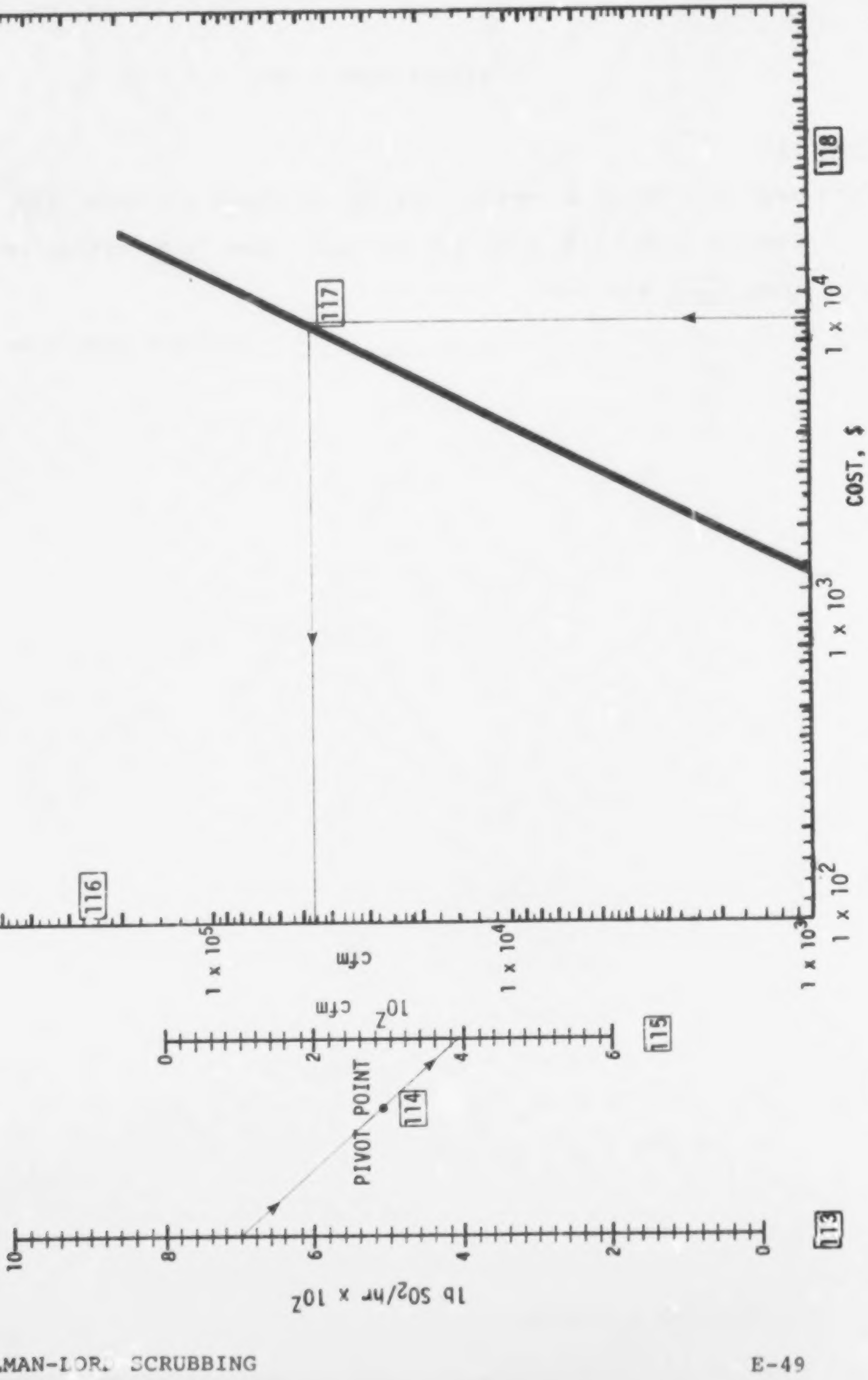


Chart 20. STRIPPER COSTS

STRIPPER PUMP COSTS

Chart 21

From page E-7, Chart 2, enter item $\boxed{8}$ on Chart 21, item $\boxed{119}$

Connect item $\boxed{119}$ with 100 ft head, item $\boxed{120}$ extend to item $\boxed{121}$ and read:

$______________ stripper pump cost $\boxed{121}$

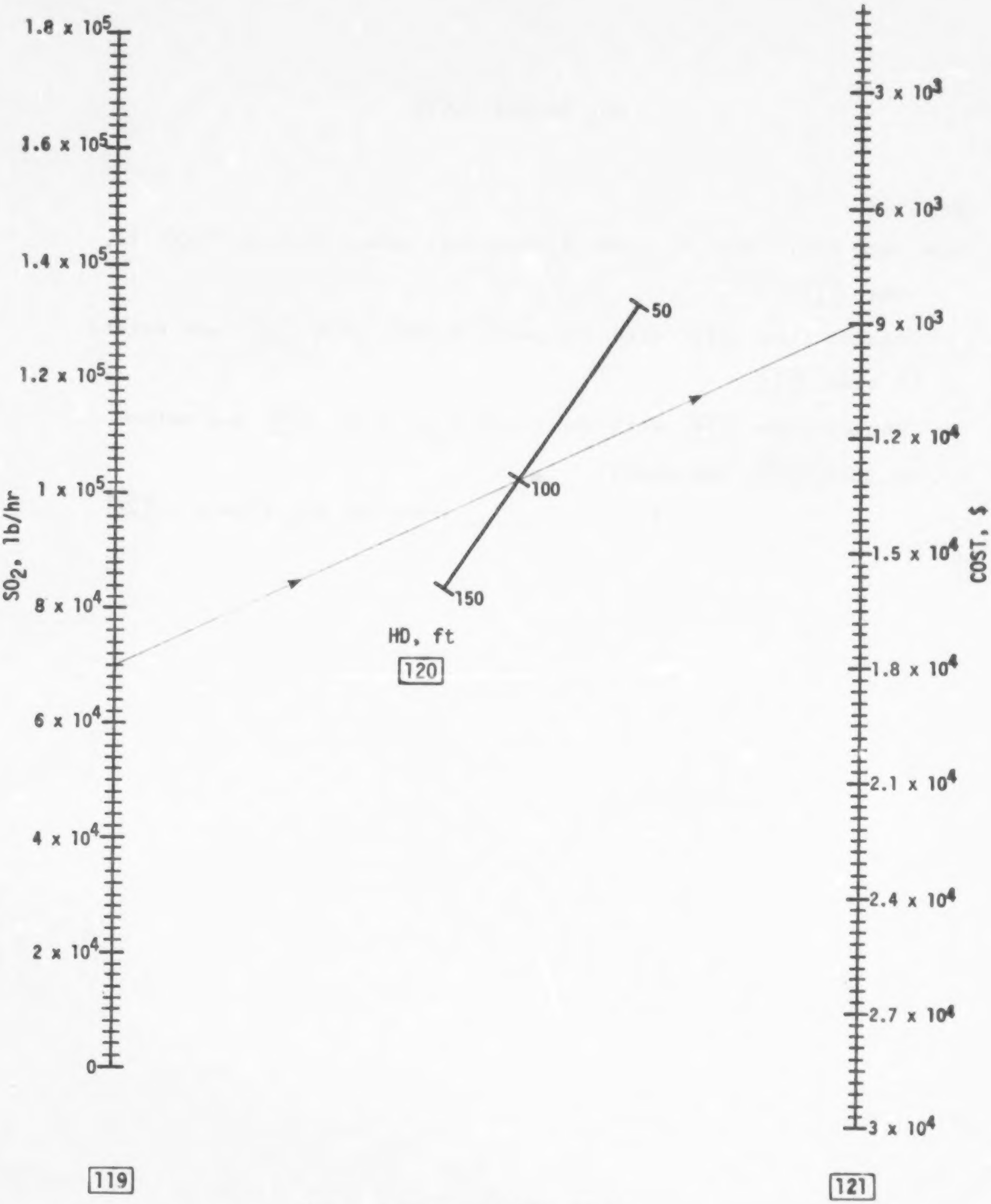


Chart 21. STRIPPER PUMP COSTS

SO_2 BLOWER COSTS

Chart 22

From page E-7, Chart 2, item $\boxed{8}$ recorded, enter this on Chart 22, item $\boxed{122}$

Connect item $\boxed{122}$ with the point 0.145, item $\boxed{123}$ and extend to item $\boxed{124}$

Connect item $\boxed{124}$ with the point C_{20}, item $\boxed{125}$ and extend to item $\boxed{126}$ and read:

$_______________ cost for SO_2 blower $\boxed{126}$

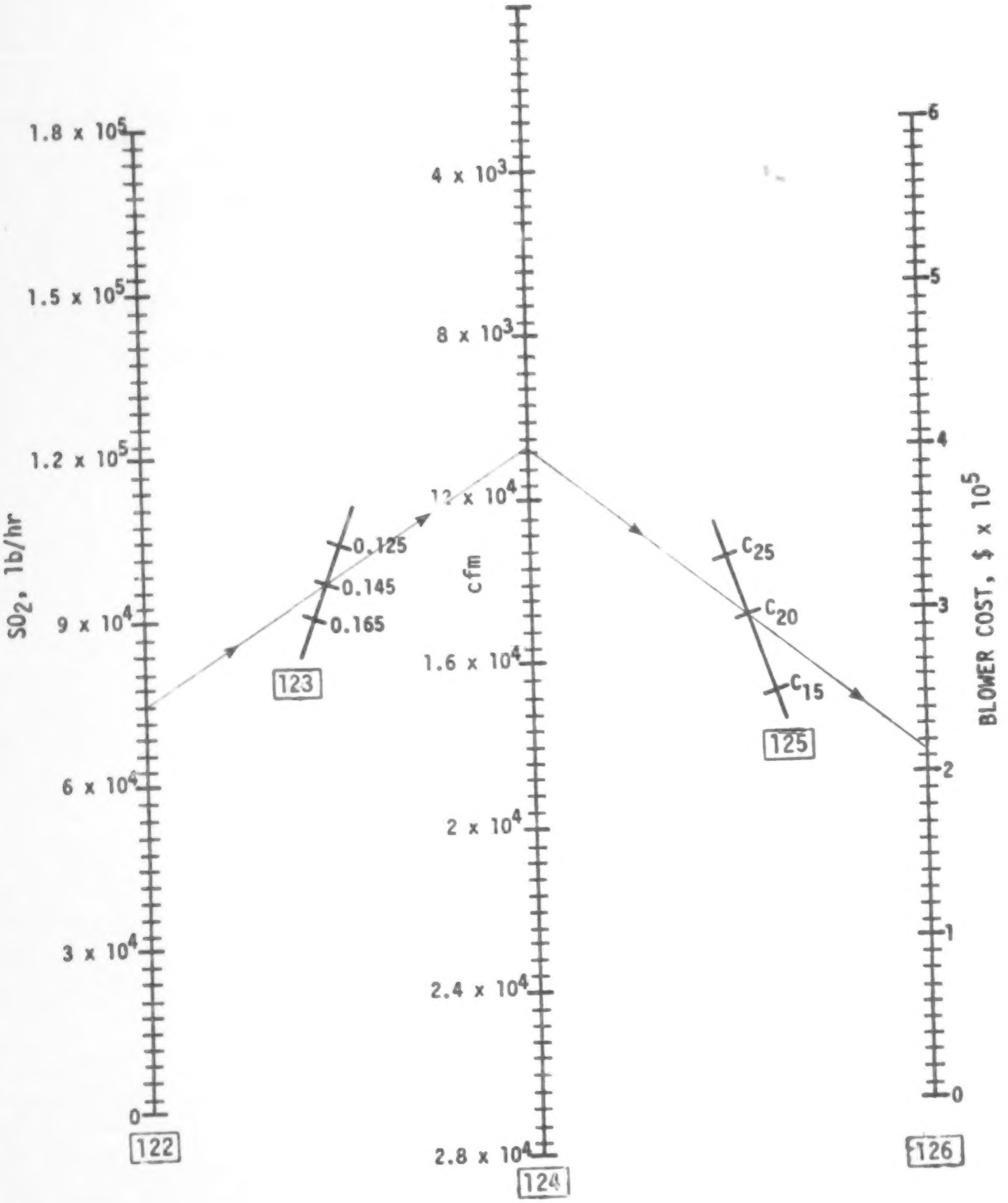


Chart 22. SO_2 BLOWER COSTS

DISSOLVING TANK, AGITATOR AND PUMP COSTS

Chart 23

From page E-7, Chart 2, enter item $\boxed{8}$ on Chart 23, item $\boxed{127}$ and move vertically upward to intersect items $\boxed{128}$, $\boxed{129}$ and $\boxed{130}$

From each of these points move horizontally to item $\boxed{131}$

and read:

\$________________cost of tank $\boxed{131}_T$

\$________________cost of agitator $\boxed{132}_A$

\$________________cost of pump $\boxed{132}_P$

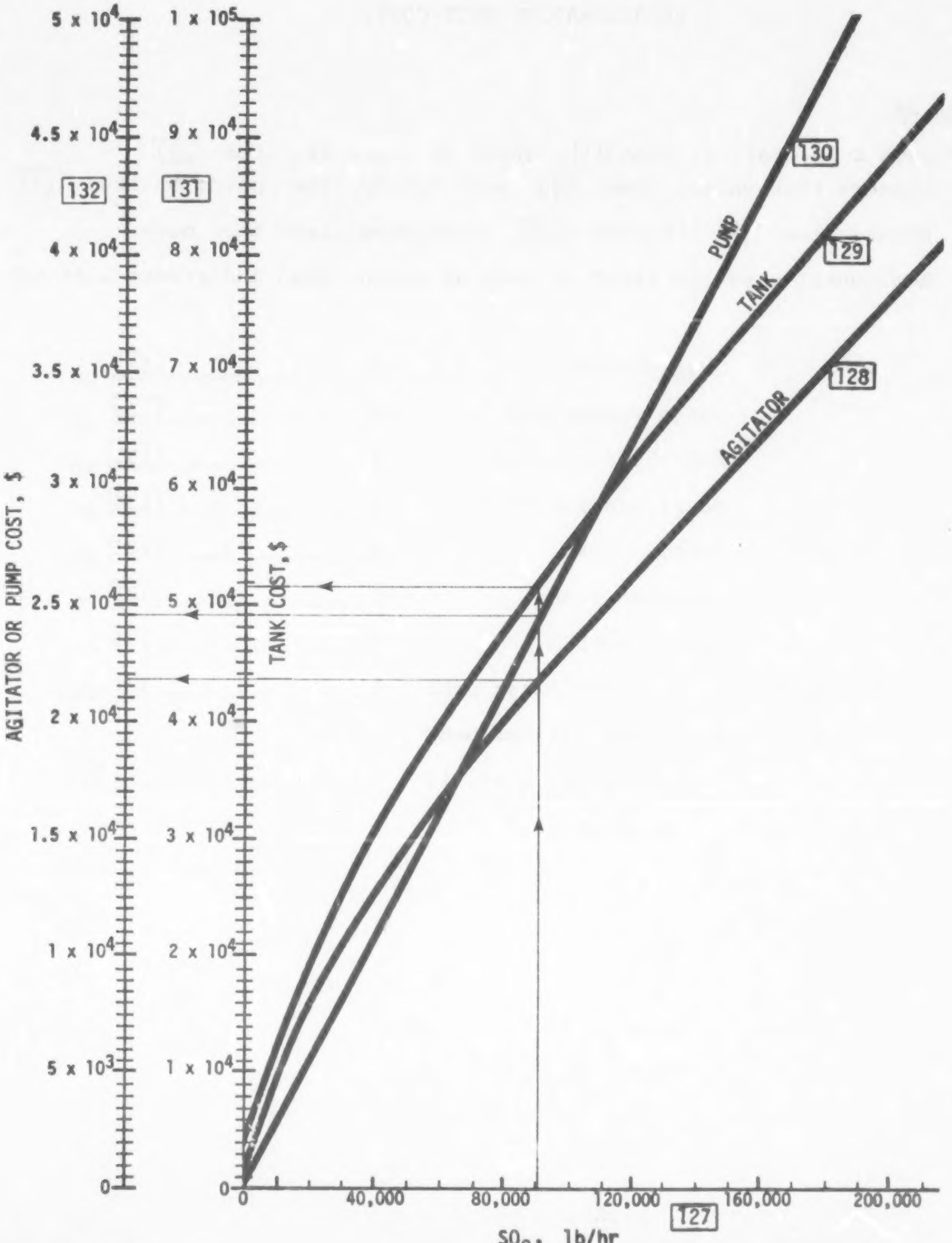


Chart 23. DISSOLVING TANK, AGITATOR AND PUMP COSTS

REFRIGERATION UNIT COSTS

Chart 24

From page E-10, Chart 3, item $\boxed{16}$, enter on Chart 24, item $\boxed{133}$

Connect this value, item $\boxed{133}$ with appropriate point on item $\boxed{134}$

Extend item $\boxed{134}$ to item $\boxed{135}$ (reference line) then move horizontally to the right or left as noted, read and record cost of:

Crystallizer $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}_{\text{CR}}$

Purge stream H.E. $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}_{\text{PS}}$

Refrigeration H.E. $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}_{\text{RE}}$

Refrigeration unit $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}_{\text{RU}}$

Glycol tank $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}_{\text{GST}}$

Centrate tank $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}_{\text{CT}}$

Glycol pump $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}_{\text{GP}}$

Variable cost of crystallizer pump $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}_{\text{VAR}}$

Total cost of crystallizer pump =

$\boxed{135}_{\text{VAR}} + 10{,}000$ $\$\_\_\_\_\_\_\_\_\_\_\boxed{135}$

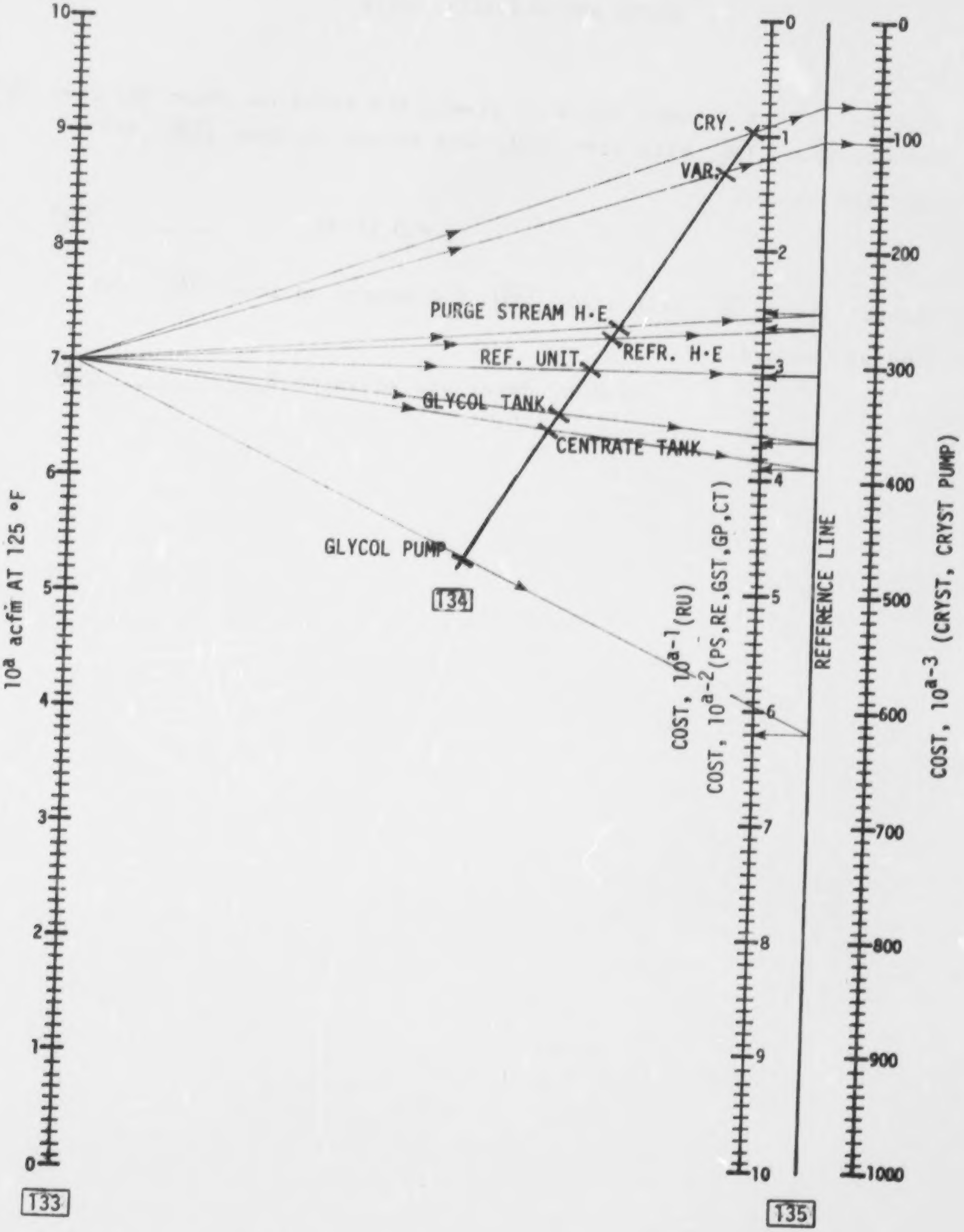


Chart 24. REFRIGERATION UNIT COSTS

DRYER AND ELEVATOR COSTS

Chart 25

From page E-7, Chart 2, read value of item $\boxed{8}$ and enter on Chart 25, item $\boxed{136}$

Connect item $\boxed{136}$ with item $\boxed{137}$ and extend to item $\boxed{138}$ and read and record:

H_2O lb/hr_______________ $\boxed{138}$

Connect item $\boxed{138}$ with item $\boxed{139}$ and extend to item $\boxed{140}$ and read and record:

Cost of dryer and elevator $\$$_______________ $\boxed{140}$

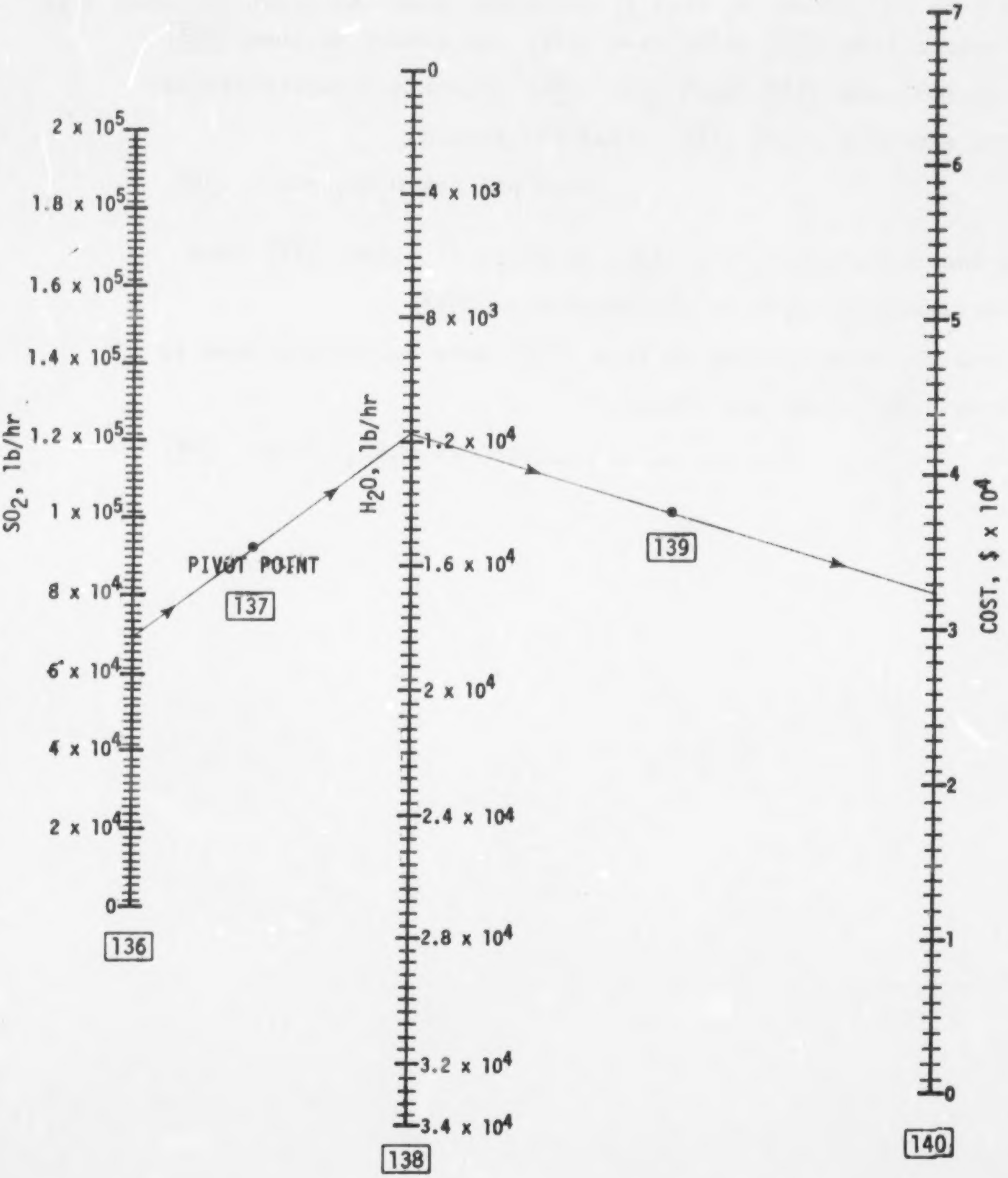


Chart 25. DRYER AND ELEVATOR COSTS

H_2SO_4 TURNKEY PLANT COST

Charts 26 and 27

From page E-7, Chart 2, item $\boxed{8}$ recorded, enter on Chart 26, item $\boxed{141}$

Connect item $\boxed{141}$ with item $\boxed{142}$ and extend to item $\boxed{143}$

Connect item $\boxed{143}$ with item $\boxed{144}$ (plant's capacity factor) and extend to item $\boxed{145}$, read and record:

__________tons per day H_2SO_4 plant $\boxed{145}$

From Chart 26, enter item $\boxed{145}$ on Chart 27, item $\boxed{146}$ move horizontally right to intersect item $\boxed{147}$

From the intersection on item $\boxed{147}$ move vertically down to item $\boxed{148}$, read and record:

$__________________cost of H_2SO_4 plant $\boxed{148}$

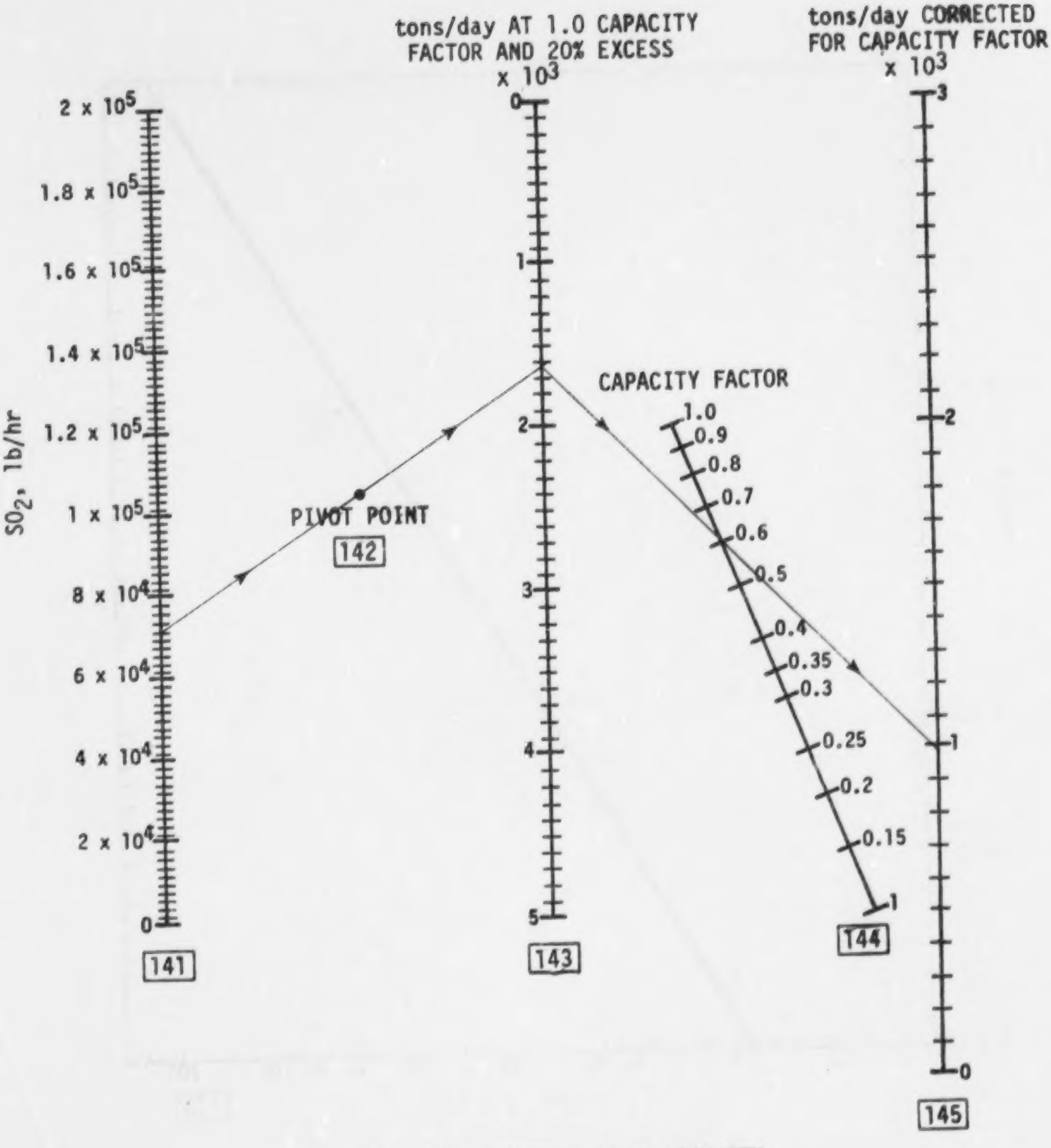


Chart 26. H_2SO_4 TURNKEY PLANT CAPACITY

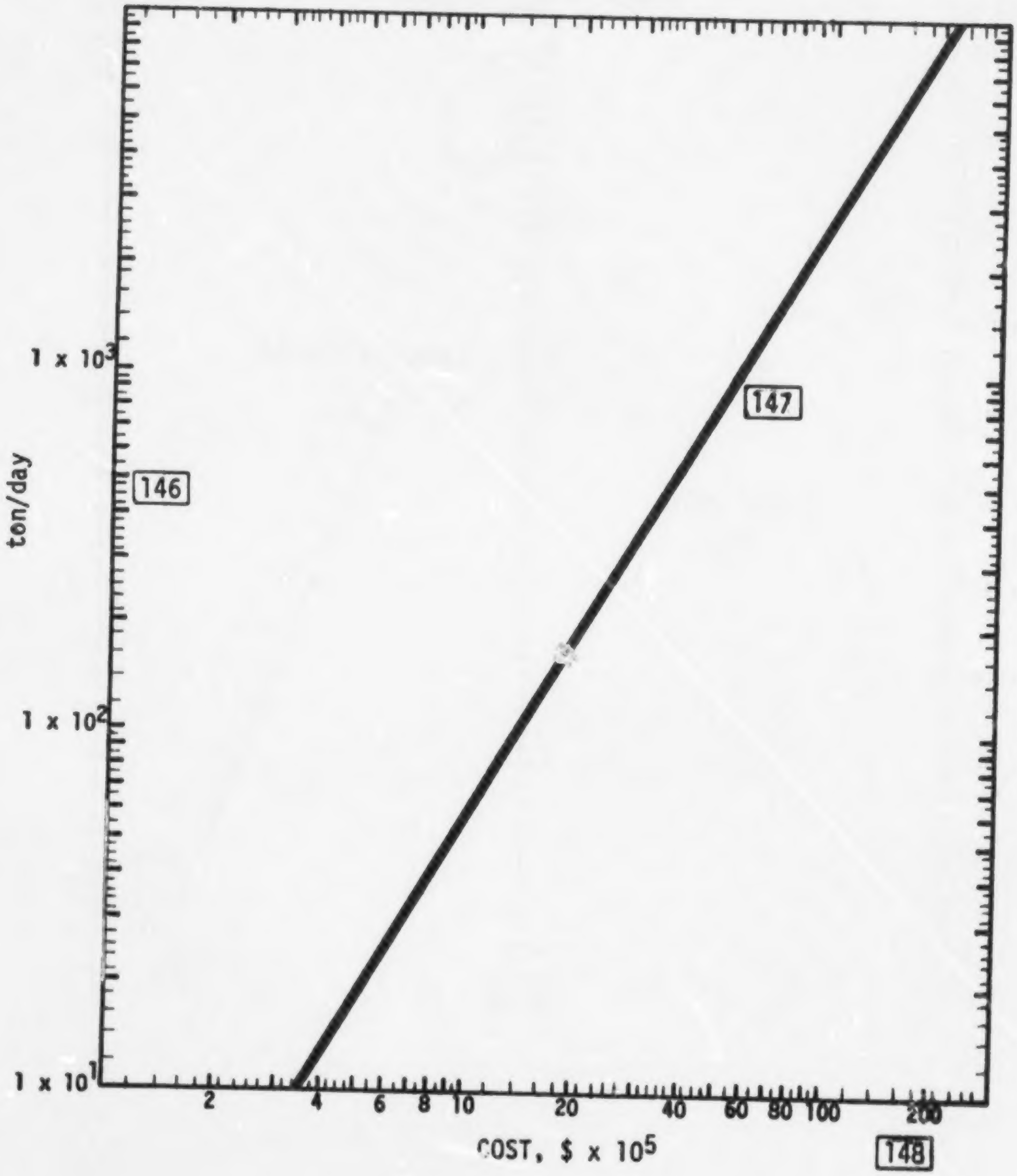


Chart 27. H_2SO_4 TURNKEY PLANT COST

MAKE-UP WATER PUMP COSTS

Chart 28

From page E-10,Chart 3, enter item $\boxed{16}$ on Chart 28, item $\boxed{149}$

Connect item $\boxed{149}$ with item $\boxed{150}$ extend to item $\boxed{151}$ read and record:

__________gpm 151

From page E-59, Chart 25, item $\boxed{138}$ recorded, enter on Chart 28, item $\boxed{152}$

Connect item $\boxed{152}$ with item $\boxed{153}$ extend to item $\boxed{154}$ read and record:

__________gpm $\boxed{154}$

Add:

$\boxed{151}$ + $\boxed{154}$ = $\boxed{155}$

____________+______________=______________total gpm make-up water

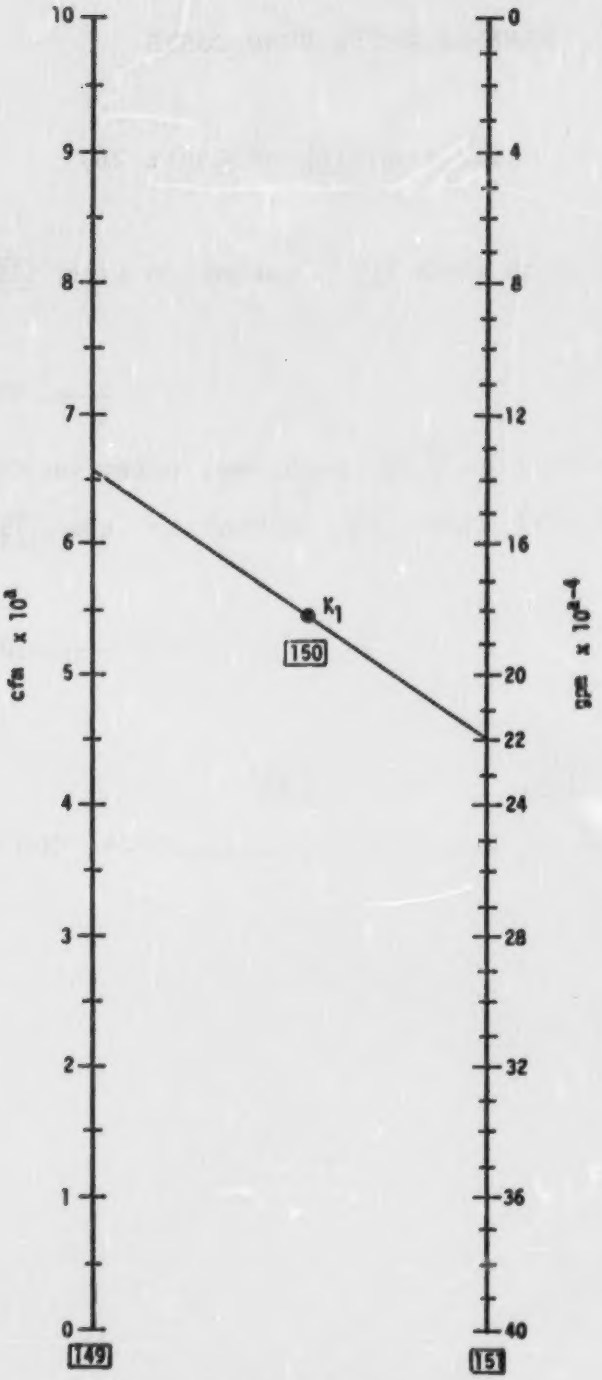


Chart 28. MAKE-UP WATER, gpm

MAKE-UP WATER PUMP COSTS

Chart 29

From page E-63, Chart 28, item $\boxed{155}$ enter on Chart 29, item $\boxed{156}$

Connect item $\boxed{156}$ with 100 ft head on item $\boxed{157}$ and extend to item $\boxed{158}$

NOTE: If gpm and head used exceeds 100 hp, divide gpm to give a whole number of pumps and proceed as above to item $\boxed{158}$, number of pumps used $\boxed{161}_{PU}$

Connect this point on item $\boxed{158}$ with 200 (cost reference) on item $\boxed{159}$ extend to item $\boxed{160}$, read and record cost:

$____________cost $\boxed{160}_{S}$

Pump costs:

$\boxed{160}_{S}$ x $\boxed{161}_{PU}$ = $\boxed{162}$ make-up water pump cost

$______________ x ______________ = $______________ $\boxed{162}$

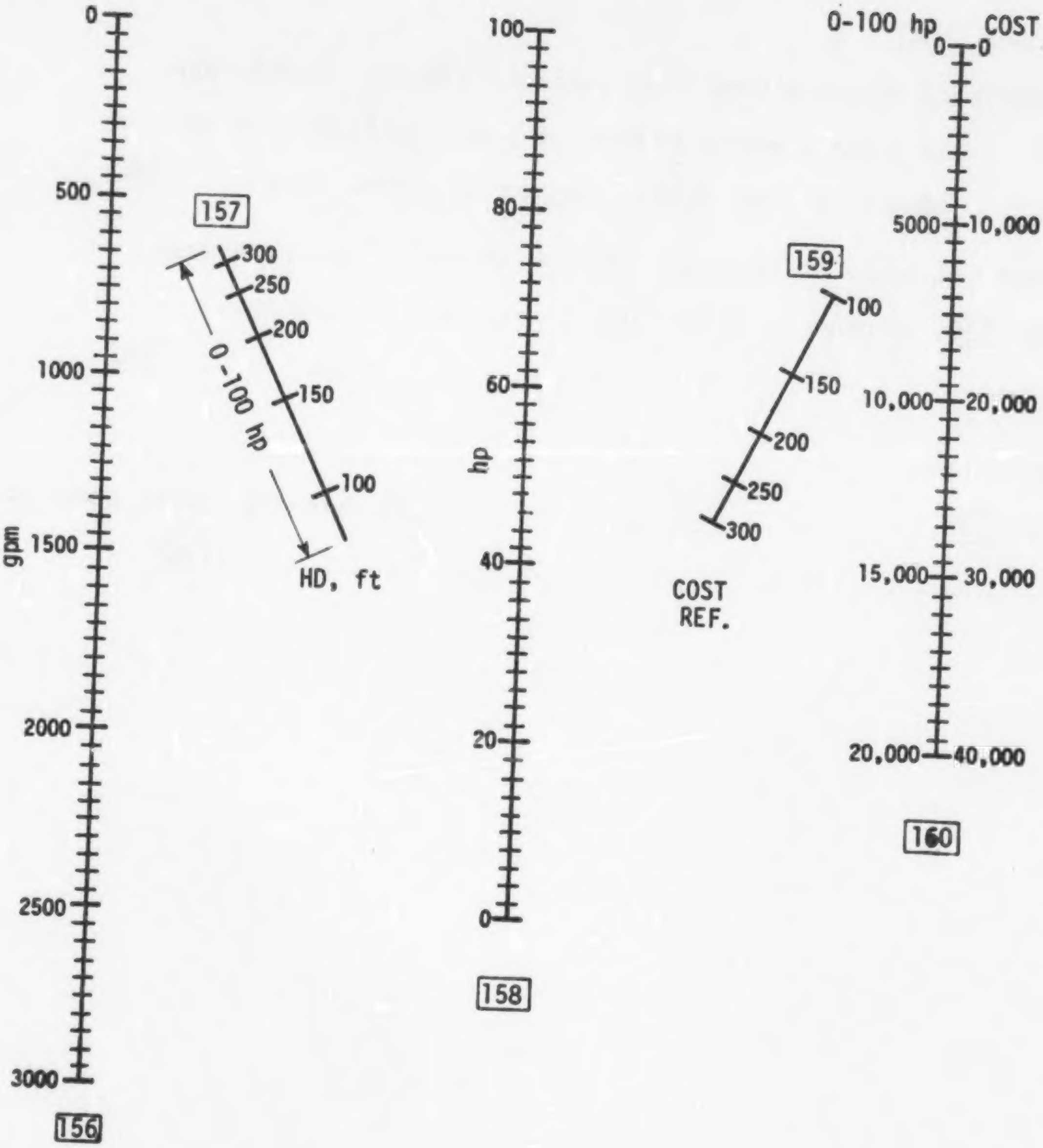


Chart 29. MAKE-UP WATER PUMP COSTS

EQUIPMENT COST

Description	Item	Total,$
1. Venturi	22 V	
2. Absorber	21 A	
3. Agitators	29	
4. Holding or circulation tank	33	
5. Pumps, recirculation, venturi	41 V	
6. Pumps, recirculation, absorber	41 A	
7. Booster fan	44	
8. Heat exchanger	56	
9. Soot blowers	60	
10. Ducting	71	
11. Ducting valves	78	
12. Feed surge and sulfite storage tanks	80	
13. Agitator for 80	81	
14. Storage silos	88	
15. Vibrators for 88	89	
16. Dissolving tank and agitators	93	
17. Dissolving tank pump	93 P	
18. Evaporator feed preheater	98 H	
19. Evaporator feed preheater pump	98 P	
20. Evaporator	102 EV	
21. Evaporator feed pump	102 P	

EQUIPMENT COST

	Description	Item	Total,$
22.	Evaporator reboiler-1st stage	$\boxed{105}$ E1	
23.	Evaporator reboiler-2nd stage	$\boxed{105}$ E2	
24.	Primary condenser	$\boxed{105}$ C	
25.	SO_2 condenser	$\boxed{105}$ SO_2	
26.	Condensate receiver	$\boxed{112}$ R	
27.	Condensate pump	$\boxed{112}$ P	
28.	Stripper	$\boxed{118}$	
29.	Stripper pump	$\boxed{121}$	
30.	SO_2 blower	$\boxed{126}$	
31.	Dissolving tank	$\boxed{131}$ T	
32.	Agitators for dissolving tank	$\boxed{132}$ A	
33.	Dissolving tank pumps	$\boxed{132}$ P	
34.	Purge stream heat exchanger	$\boxed{135}$ PS	
35.	Refrigeration unit	$\boxed{135}$ RU	
36.	Refrigeration heat exchanger	$\boxed{135}$ RE	
37.	Glycol tank	$\boxed{135}$ GST	
38.	Glycol pumps	$\boxed{135}$ GLP	
39.	Crystallizer	$\boxed{135}$ CRY	
40.	Crystallizer pump	$\boxed{135}$	
41.	Centrate tank	$\boxed{135}$ CT	
42.	Dryer and elevator	$\boxed{140}$	

EQUIPMENT COST

Description	Item	Total, $
Make-up water pump	$\boxed{162}$	________
	Total Equipment Cost	________

Total predicted equipment cost = Cost Index Factor from Chart 30 x Total Equipment cost

= ________ x ________ = $ ________

Predicted turnkey cost of H_2SO_4 plant =

H_2SO_4 Plant Cost from 148 x Cost Index Factor from Chart 30

= ________ x ________ = $ ________

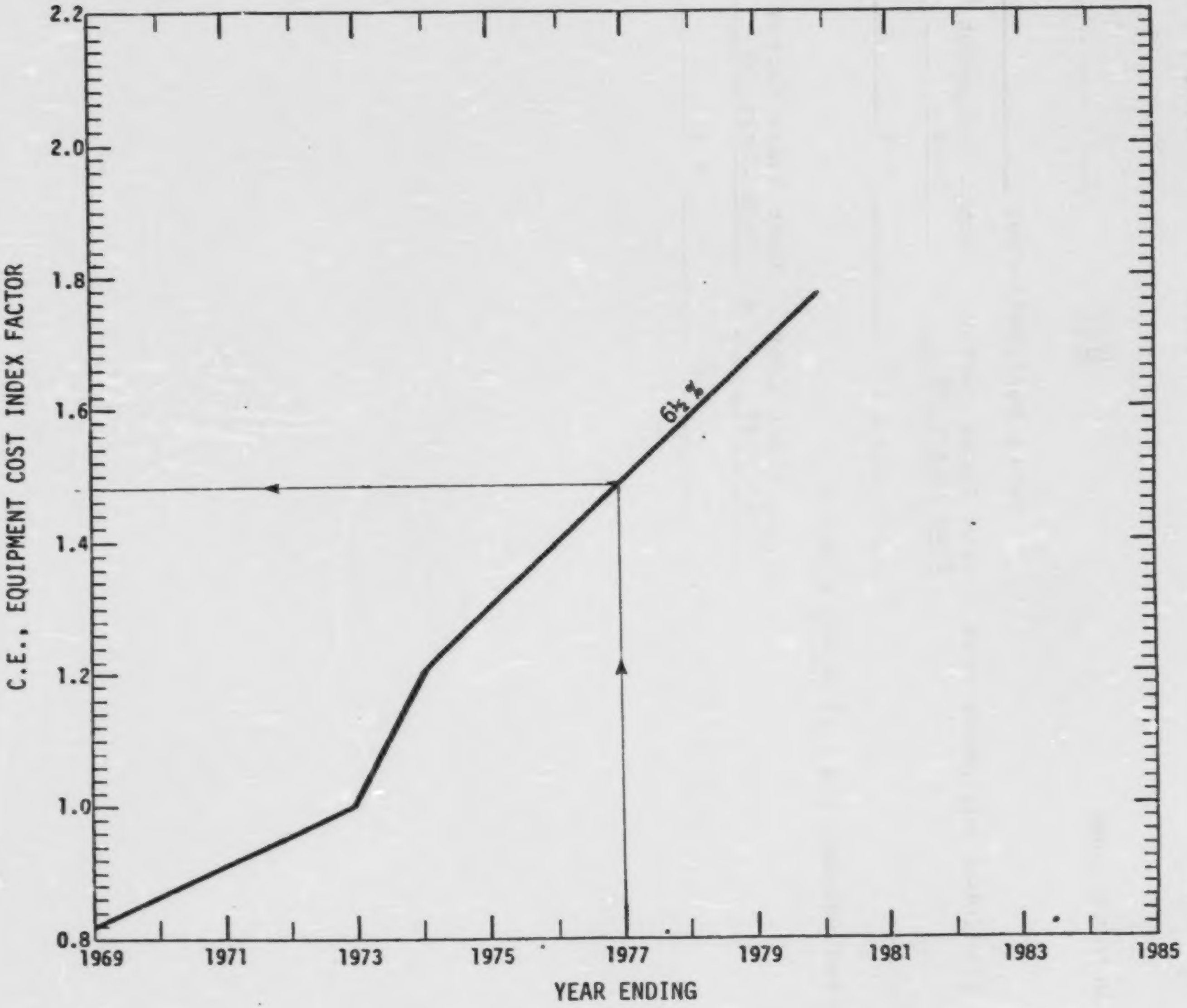


Chart 30. COST INDEX FACTOR

CAPITAL INVESTMENT COSTS--WELLMAN-LORD

Direct costs:

Select system required	Absorber	Absorber-Venturi	Cost,$
"A" Material	1.83 λ[a] 1.445 λ	1.752 λ 1.465 λ	
"B" Labor	0.98 λ 0.528 λ	0.99 λ 0.607 λ	

"C"	Retrofit	Materials and Labor		Check One
		Absorber	Absorber-Venturi	
	Easy	0	0	
	Moderate	0.047 λ	0.039 λ	
	Difficult	0.093 λ	0.077 λ	

[a] λ = Predicted Equipment cost from page E-69 = ________________

"D" Raw materials: Chart 2, item $\boxed{10}$

lb/hr Na_2Co_3

____________ x 720 x $0.024/lb[a] = ________________

"E" Predicted turnkey cost of H_2SO_4 plant

= ________________

"F" Direct costs ("A" + "B" + "C" + "D") above = ________________

"G" Direct costs ("A" through "E" incl.) above = ________________

"H" Direct costs ("A" + "B" + "C") above = ________________

Indirect costs:

"J" Interest, contractor fee and expenses, engineering, freight, offsite, taxes, start-up, spares.

0.33"G" + 0.1"H" + 0.065"A" =

__________ + ____________ + ________________ = ________________

"K" Contingency

0.2 ("J" + "F") =

0.2(__________ + __________) = $ ________________

[a] $42.00-$54.00/ton as of 12-30-74 "Chemical Marketing Report"

CAPITAL INVESTMENT COSTS--WELLMAN-LORD

"L" Total costs for Capital Investment:

"G" + "J" + "K" =

__________ + __________ + __________ = $__________

Cost/kilowatt:

$$\frac{\text{"L"}}{\text{megawatts} \times 1,000} =$$

$$\frac{\rule{3cm}{0.4pt}}{\times 1,000} = \$\rule{3cm}{0.4pt}/\text{kw}$$

TOTAL ANNUAL OPERATING COSTS--WELLMAN-LORD

aw Materials-

From page E-7, Chart 2, item $\boxed{12}$ recorded, ______________ ton/yr Na_2CO_3

From "Chemical Marketing Report" of December 30, 1974 cost/ton Na_2CO_3 is \$42.00 to \$54.00 use \$48.00/ton

_____ ton/yr Na_2CO_3 x \$ ____________ = $\boxed{163}$ yearly cost raw materials

Cost: ____________________ x \$48.00/ton = \$ __________________ $\boxed{163}$

tilities-

Electrical:

(0.03 x _______ MW x 8760 x 0. _______ weighed capacity factor from data sheet

x \$0. /KWH x 1000 KW/MW) =

MW weighed Capacity factor $\boxed{164}$ cost/yr

1774 x ___________ x 0. _______________ = \$ _______________

Water:

(total gpm) weighed capacity factor

____________ x 60 min/hr x 8760 hr/yr x 0. ______________

x $\frac{\$0.02}{1000}$ cost of water/1000 gal. = $\boxed{165}$

Chart 28, item $\boxed{155}$ total gpm x CF = $\boxed{165}$ cost/yr

10.5 x ____________________ x 0. _______________ = \$ _______________

TOTAL ANNUAL OPERATING COSTS -- WELLMAN-LORD

Utilities-

Fuel for reheat:

Chart 3, item $\boxed{16}$
combined
acfm at 125°F

[FG reheat ΔT 50°F] ; (59.4 x________________) +

Chart 2, item $\boxed{8}$
lb SO_2/hr

[evaporator feed preheater] ; (317.5 x________________) +

Chart 2, item $\boxed{8}$
lb SO_2/hr

[condensate stripper] ;(1065 x________________) +

Chart 2, item $\boxed{8}$
lb SO_2/hr

[dryer] ;(74 x________________) =

Chart 3, item $\boxed{16}$ comb.
acfm at 125°F

Chart 2, item $\boxed{8}$
lb SO_2/hr

(59.4 x________________) + (1456.5 x____________) =

$____________ $\boxed{166}$ cost/year

Operating labor-

MW's:	0-1300	1301-3000
Direct: Men/shift	5	7

(____men/shift x 8760 hr/yr x $6.50/man-hr) =

57,000 x____men/shift = $__________ $\boxed{167}$ cost/year*

TOTAL ANNUAL OPERATING COSTS--WELLMAN-LORD

Supervision: 0.15 x $\boxed{167}$**=0.15 x $\overset{\boxed{167}}{\_\_\_\_\_\_\_\_}$ = $__________ $\boxed{168}$

aintenance-

Labor and materials: 4% of "L", total capital investments

0.04 x "L"________ = $__________ $\boxed{169}$ cost/year

upplies: 15% of labor and materials:

0.006 x "L"________ = $__________ $\boxed{170}$ cost/year

verhead-

Plant: 50% of operation and maintenance:

0.5 x $\boxed{167}$**________ + $\boxed{168}$ ________ + $\boxed{169}$ ________ + $\boxed{170}$

= $__________ $\boxed{171}$ cost/year

Payroll: 20% of operating

0.2 x ($\boxed{167}$**________ + $\boxed{168}$ ________) = $__________ $\boxed{172}$ cost/year

ixed costs-

Straight line depreciation: $\dfrac{1.00}{\text{Equip. life (Plant life but not to exceed 20 yrs.)}}$ = 0.________ $\boxed{173}$ %

Interim replacement = 0.0035 $\boxed{174}$

Insurance = 0.003 $\boxed{175}$

Taxes = 0.04 $\boxed{176}$

Capital cost = 0.08 $\boxed{177}$

% of fixed investment = $\boxed{173}$ + $\boxed{174}$ + $\boxed{175}$ + $\boxed{176}$ + $\boxed{177}$ = 0.________ $\boxed{178}$ %

$\overset{\text{L}}{\_\_\_\_\_\_\_\_\_\_}$ x 0.$\overset{\boxed{178}}{\_\_\_\_\_\_\_\_}$ = __________ $\boxed{179}$ cost/year

TOTAL ANNUAL OPERATING COSTS--WELLMAN-LORD

Other costs-

Acid handling costs/year = $\$$ ____________________ $\boxed{180}$

Acid resale/year = $\$$ ____________________ $\boxed{181}$ ±

Other costs/year (indicate) $\$$ ____________________ $\boxed{182}$

Total annual cost-

$$\boxed{163} + \boxed{164} + \boxed{165} + \boxed{166} + \boxed{167}^{**} + \boxed{168} + \boxed{169} + \boxed{170} + \boxed{171} + \boxed{172}$$

$$\boxed{179} + \boxed{180} + \boxed{181} + \boxed{182} =$$

$\$$ ____________________ $\boxed{183}$ cost/year

Cost/KWH-

$$\frac{\text{Total annual cost } \boxed{183}}{8760 \text{ hr/yr} \times \_\_\_\_\_ \text{ MW} \times 1000 \text{ KW/MW}} =$$

$$(\boxed{183}\ \$\_\_\_\_\_\_\_\_\_\_\_\_ \times 1.14 \times 10^{-7}) \div \_\_\_\_\_\_\_\_\_\_ \text{ MW} =$$

$$\$\ 0.\_\_\_\_\_\_\_\_\_\_ \text{/KWH } \boxed{184}$$

* If hourly rate different than $6.50, correct $\boxed{167} \times \frac{\text{new rate}}{6.50} = \$\_\_\_\_\_\_\ \boxed{167}_C$

** $\boxed{167}_C$ if applicable

ANNUAL OPERATING COSTS

Description			Total
Raw Materials		163	$ ________
Untilities:	Electrical	164	________
	Water	165	________
	Reheat	166	________
Operations:	Labor	167	________
	Supervision	168	________
Maintenance:	Labor and Materials	169	________
	Supplies	170	________
Overhead:	Plant	171	________
	Payroll	172	________
Fixed Costs		179	________
7. Other Costs:	Acid Handling	180	________
	Acid Resale	181	________
	Other	182	________
Total Annual Costs:		183 =	$ ________

Cost/KWH ________ 183 x (1.14 x 10^{-7}) =

$ ________ /KWH

RAPID PROCEDURES FOR ESTIMATING CAPITAL AND ANNUAL OPERATING COSTS FOR FLUE GAS CLEANING SYSTEMS (FGC)

PLANT DATA

Complete the following operating data form for all boilers at the plant.

	Boiler No.			
	1	2	3	4
Maximum continuous capacity, MW				
Capactiy factor, %				
Boiler remaining life, years				
Fuel consumption/hour				
Flue gas rate, ft^3/min				
Flue gas temperature, °F				
Allowable SO_2 rate, $lb/10^6$ Btu				
Allowable particulate rate, $lb/10^6$ Btu				
Estimated duct run, ft				
Ash content of fuel, %				
Sulfur content of fuel, %				
Heating value of fuel, Btu/unit				
Efficiency of existing particulate control device, %				

Using the parameters listed above, calculate the values of the following factors to be used in the cost equations.

Preceding page blank

A: **Ash Removal Rate, ton/hr**

Using the proper emission factor from AP-42, and efficiency of existing control equipment, calculate ash removal rate (ton/hr). Add together ash removal rate for each boiler to obtain plant rate A. If no ash removal is required, use value of A = 0 in the cost equations.

S: **SO_2 Removal Rate, ton/hr**

Using the proper emission factor from AP-42, and allowable rate, calculate SO_2 removal rate (ton/hr). Add together SO_2 removal rate for each boiler to obtain total plant rate S.

G: **Plant Flue Gas Rate--ft^3/min at 300°F**

Calculate the flue gas rate at 300°F (G_1, G_2,---G_x) for each boiler using the following equation:

$$\text{Flue gas rate of 300°F} = \text{actual flue gas rate} \times \frac{760}{460 + \text{temp. of flue gas}}$$

Add $G_1 + G_2 + G_3 \text{ --- } + G_x$ to get G

N: **Number of Scrubbing Trains at the Plant**

Calculate number of trains for each boiler.

$$N_1 = \frac{G_1}{450{,}000}, \; N_2 = \frac{G_2}{450{,}000}, \; \ldots, \; N_x = \frac{G_x}{450{,}000}$$

Round off $N_1, N_2, N_3 \ldots N_x$ to next whole number.

$N = N_1 + N_2 + N_3 \ldots + N_x$ = total number of trains.

DF: Duct Factor

Calculate duct factor for each train.

$$DF_1 = \frac{\text{Estimated duct run for train 1}}{300}$$

$$DF_2 = \frac{\text{Estimated duct run for train 2}}{300} \quad \text{etc.}$$

$$\text{Average DF} = \frac{DF_1 + DF_2 + DF_3 \ldots + DF_N}{N}$$

CF: Average Capacity Factor

$$CF = \frac{CF_1 \times MW_1 + CF_2 \times MW_2 \ldots + CF_x \; MW_x}{MW_1 + MW_2 + MW_3 \ldots + MW_x}$$

CF_1 = Capacity factor for Boiler 1

MW_1 = Capacity in MW for Boiler 1

BRLY: Average Boiler Remaining Life in Years

$$BRLY = \frac{BRLY_1 \times MW_1 + BRLY_2 \times MW_2 \ldots + BRLY_x \times MW_x}{MW_1 + MW_2 \ldots + MW_x}$$

$BRLY_1$ = Boiler remaining life for Boiler 1
(if BRLY is >20 assume BRLY = 20)

The input factors discussed above are common for all FGC systems and are required for calculating the capital costs. The input factors for annual operating costs are different for each system. These factors are discussed at the beginning of each annual cost procedure.

LIME FGC CAPITAL COST

A. LIME PREPARATION	EQUATION	COST, $
Conveyor	$3800\ S + 248{,}600$	
Storage silos	$18{,}440\ S + 165{,}000$	
Slaker	$945\ S + 5338\sqrt{S}$	
Pumps and motors	$5{,}548\ S + 32{,}000$	
Storage tank	When $S<34 = 2{,}778\ S + 18{,}000$ When $S>34 = 3856\ S$	
	Subtotal - A	

B. SO_2 SCRUBBING		
Absorbers	$3.374\ G$	
Fans and motors	$0.71\ G$ (Abs only)* $0.983\ G$ (Abs + Vent)	
Pumps and motors	$0.16 + 36{,}000\ N$	
Tanks	$9.02\ \left(\frac{G}{N}\right)^{2/3} \times N + 47.64\ \left(\frac{G}{N}\right)^{1/3} \times N$	
Reheaters	$0.828\ G$	
Soot blower	$0.3605\ G + 25{,}100\ N$	
Ducting	$417.60\sqrt{GN} \times DF$	
Valves	$0.268\ G$	
	Subtotal - B	

C. SLUDGE DISPOSAL		
Clarifiers	$37{,}475\sqrt{2.0132\ S + A}$	
Vacuum filters	$15{,}093\ S + 7{,}496\ A + 310{,}400$	
Tanks and mixers	$236.48\ [2.0132\ S + A]^{2/3} + 1618.6\ [2.0132\ S + A]^{1/3}$	
Fixation chemical storage	$1229\ S + 22{,}000$	
Pumps and motors	$0.0148\ G + 2308\ S + 1{,}146\ A + 12{,}000$	

* Use only one appropriate equation.

C. **SLUDGE DISPOSAL**: (Continued)	**EQUATION**	**COST, $**
Sludge Pond	$64{,}155\sqrt{(2.1032\,S + A)\,CF \times BRLY}$	
Mobile equipment	$1207\,S + 22{,}000$	
New roadways, RR siding	$30{,}000\,N$	
	Subtotal - C	

D. **PARTICULATE REMOVAL**: (Needed only when particulate control is necessary, otherwise these costs are zero).

Venturi scrubber	$2.205\,G$	
Tanks	$9.02\left(\frac{G}{N}\right)^{2/3} \times N + 47.64\left(\frac{G}{N}\right)^{1/3} \times N$	
Pumps and motors	$0.1\,G + 36{,}000\,N$	
	Subtotal - D	
	TOTAL (A + B + C + D)	
t	ADJUSTED DIRECT COST = ESC. FACTOR x TOTAL	

INDIRECT COST

Interest during construction	0.1 t	
Field labor and expenses	0.1 t	
Contractor fees and expenses	0.05 t	
Engineering	0.10 t	
Freight	0.0125 t	
Offsite	0.03 t	
Spares	0.015 t	
Taxes	0.005 t	
Allowance for Shakedown	0.05 t	
t_1	TOTAL INDIRECT COST	
	CONTINGENCY = $0.2\,(t + t_1)$	
	GRAND TOTAL = $1.2\,(t + t_1)$	
	$\$/kW = \frac{\text{GRAND TOTAL}}{MW \times 1000}$	

LIME FGC ANNUAL OPERATING COST

Obtain following cost and mileage data for the plant under consideration:

Electricity, mills/kWh = ELCO
Lime, \$/ton = LMCO
Labor, \$/hr = LBCO
Sludge Trucking Distance, miles = TMGE

Reproduce the following plant data as computed/listed in lime capital cost estimation procedure:

Plant Capacity, MW = MW
Number of Scrubbing Trains = N
Gas Flow Rate, acfm @ 300°F = G
SO_2 Removal Rate, T/hr = S
Ash Removal Rate, T/hr = A
Capacity Factor = CF
Remaining Life = BRLY
Total Capital Cost = GRTL

Use the equations listed on the following pages to obtain annual operating cost.

A. OPERATING COST	EQUATION	COST, $
Raw Material		
Lime	8,876 x S x LMCO x CF	______
Fixation chemical	29,200(2.032S + A) x CF	______
Utilities		
Electricity*	0.044 x G x ELCO x CF (Coal burning with Abs + Vent)	______
	0.040 x G x ELCO X CF (Coal burning with Abs)	
	0.028 x G X ELCO x CF (Oil burning with Abs)	
Water	0.0142 x G x ELCO x CF	______
Reheat	0.021 x G x ELCO x CF	______
Labor		
Direct Labor*	17,520 x LBCO(N≤4)	______
	26,280 x LBCO (N=5 or 6)	
	4,380 x N x LBCO (N>6)	
Supervision	0.15 x direct labor	______
Maintenance		
Labor and Materials	0.04 x GRTL	______
Supplies	0.006 x GRTL	______
Overhead		
Plant	0.50 x (Labor + maintenance)	______

---

* Use only one appropriate equation.

Overhead (continued)	EQUATION	COST, $
Payroll	0.20 x labor	______

A. Total Operating Cost = $______

B. FIXED COST

Depreciation	GRTL/BRLY	______
Interim Replacement	0.0035 x GRTL	______
Taxes	0.04 x GRTL	______
Insurance	0.003 x GRTL	______
Capital Charges	0.09 x GRTL	______

B. Total Fixed Cost = $______

C. TRUCKING COST

Sludge Trucking	(2.0132S + A) x 29,200 x TMGE x CF	= $______

D = TOTAL ANNUAL COST = A+B+C = $______

Mills/kWh = D/(8,760 x CF x MW) ______

LIMESTONE FGC CAPITAL COST

A. LIMESTONE PREPARATION	EQUATION	COST, $
Conveyors	$8,025\ S + 248,600$	
Storage silo	$4,794\ S + 32,816$	
Ball mill	$16,050\ S + 375,000$	
Pumps and motors	$11,640\ S + 4,000\ N + 30,500$	
Storage tanks	$4,588\ S + 16,630\sqrt{S} + 234\ S^{2/3}$	
	Subtotal - A	

B. SO_2 SCRUBBING		
Absorbers	$4.2824\ G$	
Fans and motors	$0.53\ G$ (Abs. only)* $0.8425\ G$ (Abs + Vent)	
Pumps and motors	$0.232\ G + 24,000\ N$	
Tanks	$0.089\ G + 108.60\sqrt{NG}$	
Reheaters	$0.828G$	
Soot blowers	$0.3605\ G + 25,100\ N$	
Ducting	$417.60\sqrt{GN} \times DF$	
Valves	$0.268\ G$	
	Subtotal - B	

C. SLUDGE DISPOSAL		
Clarifiers	$37,475\sqrt{3.14\ S + A}$	
Vacuum filters	$23,540\ S + 7,496\ A + 310,400$	
Tanks and mixers	$236.48\ [3.14\ S + A]^{2/3} + 1618.6\ [3.14\ S + A]^{1/3}$	
Fixation chemical storage	$1582\ S + 10,940$	
Pumps and motors	$0.0148\ G + 3600\ S + 1146\ A + 12,000$	

* Use only one appropriate equation.

C. **SLUDGE DISPOSAL:** (Continued)	**EQUATION**	**COST, $**
Sludge pond	$64{,}155\sqrt{(3.14\ S + A)\ CF \times BRLY}$	
Mobile equipment	$1{,}883\ S + 22{,}000$	
New roadways, RR siding	$30{,}000\ N$	
	Subtotal - C	

D. **PARTICULATE REMOVAL:** (Needed only when particulate control is necessary, otherwise costs are not to be calculated).

Venturi scrubber	$2.205\ G$	
Tanks	$0.011\ G + 31.25\sqrt{GN}$	
Pumps and motors	$0.056\ G + 20{,}000\ N$	
	Subtotal - D	
	TOTAL: (A + B + C + D)	
t ADJUSTED DIRECT COST = ESCAL. FACTOR x TOTAL		

INDIRECT COST:

Interest during construction	0.1 t	
Field labor and expenses	0.1 t	
Contractor fees and expenses	0.05 t	
Engineering	0.1 t	
Freight	0.0125 t	
Offsite	0.03 t	
Spares	0.015 t	
Taxes	0.005 t	
Allowance for shakedown	0.05 t	
t_1 TOTAL INDIRECT COST		
CONTINGENCY $0.2\ (t + t_1)$		
GRAND TOTAL $1.2\ (t + t_1)$		
$\$/\text{kW} = \dfrac{\text{GRAND TOTAL}}{\text{MW} \times 1000}$		

LIMESTONE FGC ANNUAL OPERATING COST

Obtain following cost and mileage data for the plant under consideration:

Electricity, mills/kWh = ELCO
Limestone, \$/ton = LSCO
Labor, \$/hr = LBCO
Sludge Trucking Distance, miles = TMGE

Reproduce the following plant data as computed/listed in limestone capital cost estimation procedure:

Plant Capacity, MW = MW
Number of Scrubbing Trains = N
Gas Flow Rate, acfm @ 300°F = G
SO_2 Removal Rate, T/hr = S
Ash Removal Rate, T/hr = A
Capacity Factor = CF
Remaining Life = BRLY
Total Capital Cost = GRTL

Use the equations listed on the following pages to obtain annual operating cost.

A. OPERATING COST	EQUATION	COST, $
Raw Material		
Limestone	18,747 x S x LSCO x CF	
Fixation Chemical	29,200(3.14S + A)x CF	
Utilities		
Electricity*	0.044 x G x ELCO x CF (Coal burning with Abs + Vent)	
	0.040 x G x ELCO X CF (Coal burning with Abs)	
	0.028 x G X ELCO x CF (Oil burning with Abs)	
Water	(0.129G + 2520S) x 0.0049 x ELCO x CF	
Reheat	0.021 x G x ELCO x CF	
Labor		
Direct Labor*	17,520 x LBCO($N \le 4$)	
	26,280 x LBCO ($N=5$ or 6)	
	4,380 x N x LBCO ($N>6$)	
Supervision	0.15 x direct labor	
Maintenance		
Labor and Materials	0.04 x GRTL	
Supplies	0.006 x GRTL	
Overhead		
Plant	0.50 x (Labor + maintenance)	

---

* Use only one appropriate equation.

Overhead (continued)	**EQUATION**	**COST, $**
Payroll	0.20 x labor	______

A. Total Operating Cost = $______

B. **FIXED COST**

Depreciation	GRTL/BRLY	______
Interim Replacement	0.0035 x GRTL	______
Taxes	0.04 x GRTL	______
Insurance	0.003 x GRTL	______
Capital Charges	0.09 x GRTL	______

B. Total Fixed Cost = $______

C. **TRUCKING COST**

Sludge trucking	(3.14S + A) x 29,200 x TMGE x CF	= $______

D = TOTAL ANNUAL COST = A+B+C = $

Mills/kWh = D/(8,760 x CF x MW) = ______

DOUBLE ALKALI FGC CAPITAL COST

A. Na_2CO_3 PREPARATION	EQUATION	COST, $
Storage silos and conveyors	82,040 + 465 S	
Feed tank	$29.19\ S^{2/3} + 55.33\ S^{1/3}$	
Pumps and motors	8,000	
	Subtotal - A	
B. LIME PREPARATION		
Storage silos and conveyors	When $S<35 = 5732\ S + 262,000$ When $D \overline{>} 35 = 6008\ S + 244,400$	
Slaker	$472.44\ S + 2,669\sqrt{S}$	
Slaker pump and motor	260 S + 7,000	
	Subtotal - B	
C. SO_2 SCRUBBING		
Absorber	1.347 G	
Fan and motor	0.39 G (Abs + Vent)* 0.265 G (Abs only)	
Pumps and motors	14,000 N + 0.0251 G	
Tanks	$3.192\ (\frac{G}{N})^{2/3} \times N + 20\ (\frac{G}{N})^{1/3} \times N$	
Reheater	0.251 G	
Soot blower	0.0986 G	
Ducting	$160\sqrt{GN} \times DF$	
Valves	0.103 G	
	Subtotal - C	

* Use only one appropriate equation.

D. **REGENERATION AND SLUDGE DISPOSAL**	**EQUATION**	**COST, $**
Reactor	When $S<26.75 = 2000\ S + 8694\sqrt{S}$ When $S>26.75 = 1589\ S + 9235\sqrt{S}$	______
Fixation silos	$5470 + 379\ S$	______
Clarifiers	$14{,}990\sqrt{2.1\ S + A}$	______
Vacuum filters	$3{,}936\ S + 1874\ A + 77{,}600$	______
Tanks and mixers	$118.24\ [2.1\ S + A]^{2/3} + 809.29\ [2.1\ S + A]^{1/3}$	______
Pumps and motors	$0.0037\ G + 602\ S + 286.4\ A + 3{,}000$	______
	Subtotal - D	______

E. **PARTICULATE REMOVAL:** (Needed only when particulate control is necessary otherwise, these costs are not to be calculated).

Venturi scrubber	$0.735\ G$	______
Tanks	$3.192\ (\frac{G}{N})^{2/3} \times N + 20\ (\frac{G}{N})^{1/3} \times N$	______
Pumps and motors	$14{,}000\ N + 0.0251\ G$	______
	Subtotal - E	______

a Total equipment cost = (A + B + C + D + E) ______

b Total installed cost* = Absorber only 3.397 x a

Absorber + venturi 3.389 x a ______

c Sludge pond cost = $64{,}155\sqrt{(2.1\ S + A)\ CF \times BRLY}$ ______

d New roadways, RR siding = 30,000 N ______

t ADJUSTED DIRECT COST = ESC. FACTOR x (b + c + d) ______

* Use only one appropriate equation.

INDIRECT COSTS	EQUATION	COST, $
Interest during construction	0.1 t	______
Field labor and expenses	0.1 t	______
Contractor fees and expenses	0.05 t	______
Engineering	0.1 t	______
Freight	0.0125 t	______
Offsite	0.03 t	______
Spares	0.015 t	______
Taxes	0.005 t	______
Allowance for shakedown	0.05 t	______

t_1 TOTAL INDIRECT COST ______

CONTINGENCY = $0.2\ (t + t_1)$ ______

GRAND TOTAL = $1.2\ (t + t_1)$ ______

$$\$/\text{kW} = \frac{\text{GRAND TOTAL}}{\text{MW} \times 1000}$$ ______

DOUBLE ALKALI FGC ANNUAL OPERATING COST

Obtain following cost and milage data for the plant under consideration:

Electricity, mills/kWh = ELCO
Lime, $/ton = LSCO
Soda Ash, $/ton = SACO
Labor, $/hr = LBCO
Sludge Trucking Distance, miles = TMGE

Reproduce the following plant data as computed/listed in double alkali capital cost estimation procedure:

Plant Capacity, MW = MW
Number of Scrubbing Trains = N
Gas Flow Rate, acfm @ 300°F = G
SO_2 Removal Rate, T/hr = S
Ash Removal Rate, T/hr = A
Capacity Factor = CF
Remaining Life = BRLY
Total Capital Cost = GRTL

Use the equations listed on the following pages to obtain annual operating cost.

A. OPERATING COST	EQUATION	COST, $
Raw Material		
Lime	8,876 x S x LMCO x CF	
Soda Ash	727 x S x SACO x CF	
Fixation Chemical	29,200(2.0132S + A)x CF	
Utilities		
Electricity*	0.044 x G x ELCO x CF (Coal burning with Abs + Vent)	
	0.040 x G x ELCO X CF (Coal burning with Abs)	
	0.028 x G X ELCO x CF (Oil burning with Abs)	
Water	0.0142 x G x ELCO x CF	
Reheat	0.021 x G x ELCO x CF	
Labor		
Direct Labor*	17,520 x LBCO($N \le 4$)	
	26,280 x LBCO (N=5 or 6)	
	4,380 x N x LBCO (N>6)	
Supervision	0.15 x direct labor	
Maintenance		
Labor and Materials	0.04 x GRTL	
Supplies	0.006 x GRTL	
Overhead		
Plant	0.50 x (Labor + maintenance)	

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* Use only one appropriate equation.

Overhead (continued)	EQUATION	COST, $
Payroll	0.20 x labor	______

A. Total Operating Cost = $______

B. **FIXED COST**

Depreciation	GRTL/BRLY	______
Interim Replacement	0.0035 x GRTL	______
Taxes	0.04 x GRTL	______
Insurance	0.003 x GRTL	______
Capital Charges	0.09 x GRTL	______

B. Total Fixed Cost = $______

C. **TRUCKING COST**

Sludge trucking	(2.0132S + A) x 29,200 x TMGE x CF	= $______

D = TOTAL ANNUAL COST = A+B+C = $______

Mills/kWh = D/(8,760 x CF x MW) = ______

MAGNESIUM OXIDE FGC CAPITAL COST

		EQUATION	COST, $
A.	MgO PREPARATION		
	Storage silos	When $S \geq 9$: $7527\ S + 115{,}480$ When $S < 9$: $4754\ S + 16{,}436$	
	Slurry tank	$1395.3\ S + 7960\sqrt{S}$	
	Pump and motor	$500\ S + 2{,}000$	
		Subtotal - A	
B.	SO_2 SCRUBBING		
	Absorbers	$0.898\ G$	
	Fans and motors	Abs $0.208\ G$* Abs + vent $0.312\ G$	
	Pumps and motors	$0.083\ G + 16{,}000\ N$	
	Tanks	$0.087\ G + 62.77\sqrt{GN}$	
	Reheater	$0.1873\ G$	
	Soot blower	$0.0986\ G$	
	Ducting	$160\sqrt{GN} \times DF$	
	Valves	$0.103\ G$	
		Subtotal - B	
C.	PURGE TREATMENT AND REGENERATION		
	Storage silo	$12{,}110\ S + 40{,}000$	
	Centrifuge	$0.215\ G$	
	Dryer	$0.15\ G + 200{,}000$	
	Centrate tank and pump	$0.007\ G + 9{,}000$	
	Pump and motor	$0.00526\ G$	
		Subtotal - C	

* Use only one appropriate equation.

D. **PARTICULATE REMOVAL**	**EQUATION**	**COST, $**
(Calculate these costs only if particulate removal is involved).		
Venturi scrubber	$0.735\ G$	
Tanks	$3.192 \left(\frac{G}{N}\right)^{2/3} \times N + 20\left(\frac{G}{N}\right)^{1/3} \times N$	
Pumps and motors	$0.0568\ G + 1902\ A + 12{,}000\ N + 3{,}000$	
Calciner	$29{,}800\sqrt{A}$	
Dust collectors	$0.0533\ G + 90{,}000$	
	Subtotal - D	

a Total equipment cost = (A + B + C + D)

b Total installed cost* = absorber only = 3.243 a

absorber and venturi = 3.287 a

c Sludge pond = $64{,}155\sqrt{A \times CF \times BRLY}$

d New roadways, RR siding = 30,000 N

t ADJUSTED DIRECT COST = ESC. FACTOR x (b + c + d)

INDIRECT COST

Interest during construction	0.1 t	
Field labor and expenses	0.1 t	
Contractor fees and expenses	0.05 t	
Engineering	0.1 t	
Freight	0.0125 t	
Offsite	0.03 t	
Spares	0.015 t	
Taxes	0.005 t	
Allowance for shakedown	0.05 t	

t_1 TOTAL INDIRECT COST

CONTINGENCY 0.2 ($t + t_1$)

GRAND TOTAL 1.2 ($t + t_1$)

$\$/\text{kW} = \frac{\text{GRAND TOTAL}}{\text{MW} \times 1000}$

* Use only one appropriate equation.

MAGNESIUM OXIDE FGC ANNUAL OPERATING COST

Obtain following cost and mileage data for the plant under consideration:

Electricity, mills/kWh = ELCO
MgO, \$/ton = MGCO
Coke, \$/ton = COKC

Labor, \$/hr = LBCO
Sludge Trucking Distance, miles = TMGE
Fuel Oil, \$/gal. = FOLC

Reproduce the following plant data as computed/listed in MgO capital cost estimation procedure:

Fuel Sulfur Content, percent = PSC
Plant Capacity, MW = MW
Number of Scrubbing Trains = N
Gas Flow Rate, acfm @ 300°F = G
SO_2 Removal Rate, T/hr = S
Ash Removal Rate, T/hr = A
Capacity Factor = CF
Remaining Life = BRLY
Total Capital Cost = GRTL

Use the equations listed on the following pages to obtain annual operating cost.

A. OPERATING COST	EQUATION	COST, $
Raw Material		
MgO	608.8 x S x CF x MGCO	________
Coke	0.000182G x PSC x CF x COKC	________
Utilities		
Electricity*	0.044 x G x ELCO x CF (Coal burning with Abs + Vent)	________
	0.04 x G x ELCO X CF (Coal burning with Abs)	
	0.028 x G X ELCO x CF (Oil burning with Abs)	
Water	0.0172 x G x ELCO x CF	________
Reheat	(0.021 x ELCO + 3.18 x PSC x FOLC) x G x CF	________
Labor		
Direct Labor*	17,520 x LBCO($N \leq 4$)	________
	26,280 x LBCO ($N=5$ or 6)	
	4,380 x N x LBCO ($N>6$)	
Supervision	0.15 x direct labor	________
Maintenance		
Labor and Materials	0.04 x GRTL	________
Supplies	0.006 x GRTL	________
Overhead		
Plant	0.50 x (Labor + maintenance)	________

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* Use only one appropriate equation.

	Overhead (continued)	EQUATION	COST, $
	Payroll	0.20 x labor	________

A. Total Operating Cost = $________

B.	FIXED COST		
	Depreciation	GRTL/BRLY	________
	Interim Replacement	0.0035 x GRTL	________
	Taxes	0.04 x GRTL	________
	Insurance	0.003 x GRTL	________
	Capital Charges	0.09 x GRTL	________

B. Total Fixed Cost = $________

C. TRUCKING COST

Sludge Trucking 29,200 x TMGE x A X CF = $________

D = TOTAL ANNUAL COST = A+B+C = $________

Mills/kWh = D/(8,760 x CF x MW) = ________

WELLMAN LORD FGC CAPITAL COST

		EQUATION	COST, $
A.	Na_2CO_3 PREPARATION		
	Storage silo	10,800 + 5,993 S	
	Vibrating feeder	3,750 + 2 S	
	Storage tank	2,185.5 $S^{2/3}$ + 17,103 $S^{1/3}$	
	Agitators	9,000 + 1,300 $S^{2/3}$	
	Pumps and motors	1,200 + 56.64 S	
		Subtotal - A	
B.	SO_2 SCRUBBING		
	Absorbers	5.025 G	
	Fans and motors	Abs only = 0.3806 G* Abs + vent = 0.5552 G	
	Pumps and motors	0.147 G	
	Reheaters	0.877 G	
	Soot blowers	0.361 G + 25,100 N	
	Ducting	$417.60\sqrt{GN}$ x D.F.	
	Valves	0.268 G	
		Subtotal - B	
C.	PURGE TREATMENT		
	Refrigeration unit	0.1428 G	
	Heat exchanger	0.022 G	
	Tanks	780 $S^{2/3}$ + 8414 $S^{1/3}$ + 0.018 G	
	Dryer	14,000 + 1,036 S	
	Elevator	10,000	
	Pumps and motors	0.04844 G + 26,130 S + 4,000	

* Use only one appropriate equation.

C. **PURGE TREATMENT:** (Continued)	**EQUATION**	**COST, $**
Centrifuge	0.2964 G	
Crystallizer	0.343 G	
Storage silo	10,800 + 5,993 S	
Feeder	3,750 + 2 S	
New roadways, RR siding	30,000 N	
	Subtotal - C	
D. **REGENERATION**		
Pumps and motors	$75{,}000 + 4{,}992\ S^{2/3} + 30{,}781\ S$	
Evaporators and reboilers	$463{,}880\ S + 23{,}624\ S^{2/3}$	
Heat exchangers	64,603 S	
Tanks	$13{,}707\ S^{2/3}$	
Stripper	$3{,}500 + 37{,}170\sqrt{S}$	
Blower	20,300 S	
	Subtotal - D	
E. **PARTICULATE REMOVAL:** (Needed only when particulate control is required, otherwise these costs are not to be calculated).		
Venturi scrubber	2.205 G	
Tanks	$0.011\ G + 31.52\sqrt{GN}$	
Pumps and motors	0.056 G + 20,000 N	
	Subtotal - E	
	TOTAL = (A + B + C + D + E)	
t ADJUSTED DIRECT COST = ESC. FACTOR x TOTAL		

INDIRECT COSTS	EQUATION	COST, $
Interest during construction	0.1 x t	
Field labor and expenses	0.1 x t	
Contractor fees and expenses	0.05 x t	
Engineering	0.1 x t	
Freight	0.0125 x t	
Offsite	0.03 x t	
Spares	0.015 x t	
Taxes	0.005 x t	
Allowance for shakedown	0.05 x t	
Acid plant	$880{,}133 \times (S \times CF)^{0.596}$	
	t1 TOTAL INDIRECT COST	
	CONTINGENCY $0.2\ (t + t_1)$	
	GRAND TOTAL $1.2\ (t + t_1)$	
	$\$/kW = \frac{\text{GRAND TOTAL}}{\text{MW} \times 1000}$	

WELLMAN LORD FGC ANNUAL OPERATING COST

Obtain following cost data for the plant under consideration:

Electricity, mills/kWh = ELCO
Soda Ash, $/ton = SASH

Labor, $/hr = LBCO
Sludge Trucking Distance, miles = TMGE
H_2SO_4 Market Cost, $/ton = SADC
Na_2SO_4 Market Cost, $/ton = NATC

Reproduce the following plant data as computed/listed in Wellman-Lord capital cost estimation procedure:

Plant Capacity, MW = MW
Number of Scrubbing Trains = N
Gas Flow Rate, acfm @ 300°F = G
SO_2 Removal Rate, T/hr = S
Ash Removal Rate, T/hr = A
Capacity Factor = CF
Remaining Life = BRLY
Total Capital Cost = GRTL

Use the equations listed on the following pages to obtain annual operating cost.

A.	OPERATING COST	EQUATION	COST, $
	Raw Material		
	Soda Ash	972 x SASH x CF x S	______
	Utilities		
	Electricity	0.05 x G x ELCO x CF	______
	Water	(0.022G + 3500S) x ELCO x CF	______
	Reheat	(0.021G + 15,400S) x ELCO x CF	______
	Labor		
	Direct Labor*	17,520 x LBCO($N \le 4$)	______
		26,280 x LBCO ($N=5$ or 6)	
		4,380 x N x LBCO ($N>6$)	
	Supervision	0.15 x direct labor	______
	Maintenance		
	Labor and Materials	0.04 x GRTL	______
	Supplies	0.006 x GRTL	______
	Overhead		
	Plant	0.50 x (Labor + maintenance)	______

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* Use only one appropriate equation.

Overhead (continued)	EQUATION	COST, $
Payroll	0.20 x labor	________

A. Total Operating Cost = $________

B. FIXED COST

Depreciation	GRTL/BRLY	________
Interim Replacement	0.0035 x GRTL	________
Taxes	0.04 x GRTL	________
Insurance	0.003 x GRTL	________
Capital Charges	0.09 x GRTL	________

B. Total Fixed Cost = $________

C. CREDITS

H_2SO_4	11,826 x S x CF x SADC	________
Na_2SO_4	874 x S x CF x NATC	________

C. Total Credit = $________

D. TOTAL ANNUAL COST = A + B - C = $________

Mills/kWh = D/(8,760 x CF x MW) = ________

APPENDIX G

METRIC SYSTEM CONVERSION FACTORS

APPENDIX G. METRIC SYSTEM CONVERSION FACTORS

Length				
Units		cm	m	
1 in.	=	2.54	0.0254	
1 ft	=	30.48	0.3048	
1 yd	=	91.44	0.9144	
1 mile	=	1.609344×10^5	1.609344×10^3	
Area				
Units		cm^2	m^2	
1 $in.^2$	=	6.4516	6.4516×10^{-4}	
1 ft^2	=	929.0304	0.09290304	
1 yd^2	=	8361.273	0.8361273	
1 $mile^2$	=	2.589988×10^{10}	2.589988×10^6	
Volume				
Units		cm^3	liter	
1 $in.^3$	=	16.38706	0.01638706	
1 ft^3	=	28316.85	28.31685	
1 qt	=	946.353	0.946353	
1 gal (U.S.)	=	3785.412	3.785412	
Mass				
Units		g	kg	Metric ton
1 oz (avdp)	=	28.34952	0.02834952	
1 lb (avdp)	=	453.5924	0.4535924	
1 ton	=	907184.7	907.1837	0.9071847
Energy				
Units		Btu	kWh	
1 cal	=	3.965667×10^{-3}	$1.1622222... \times 10^{-6}$	